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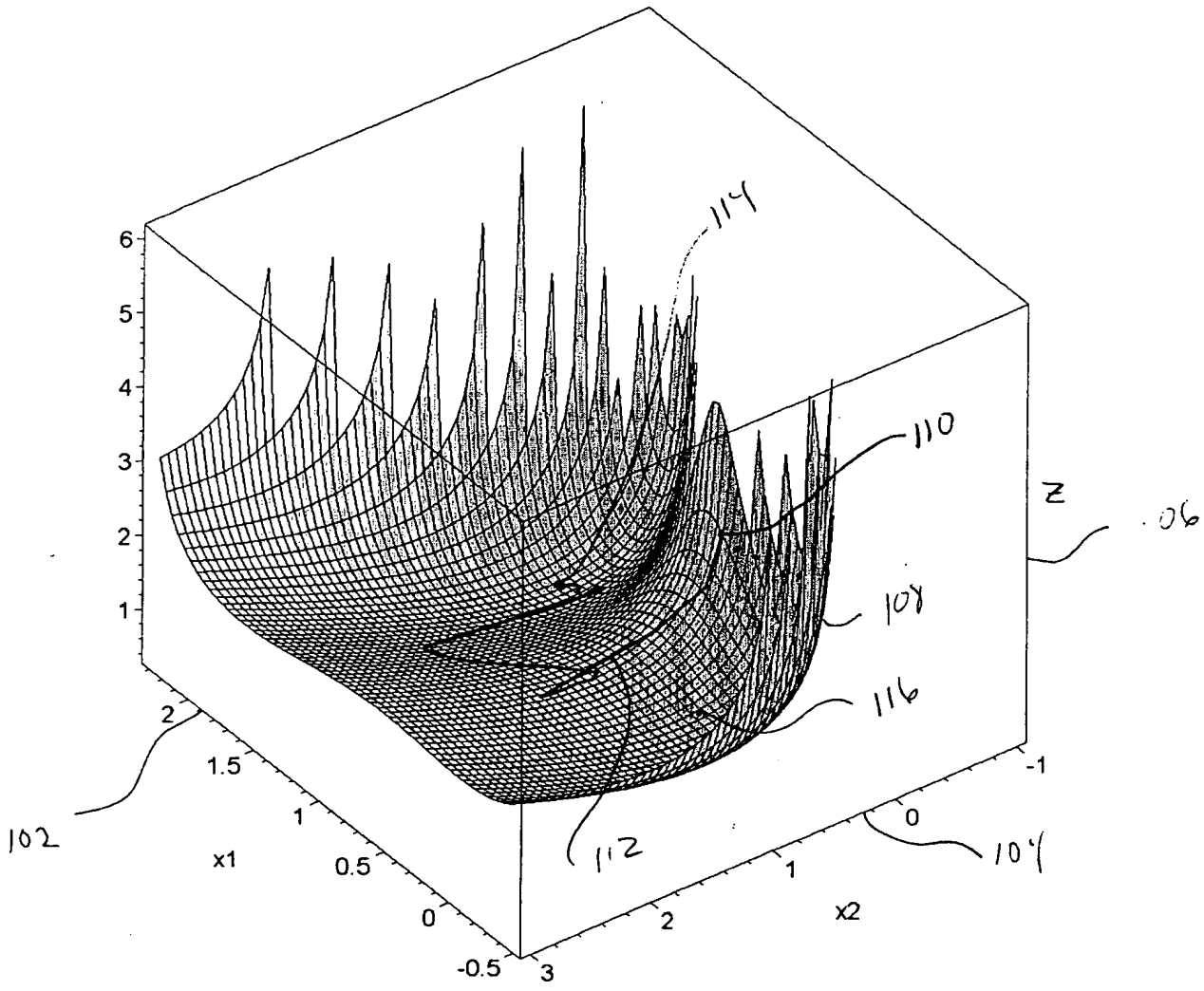


Figure 1A

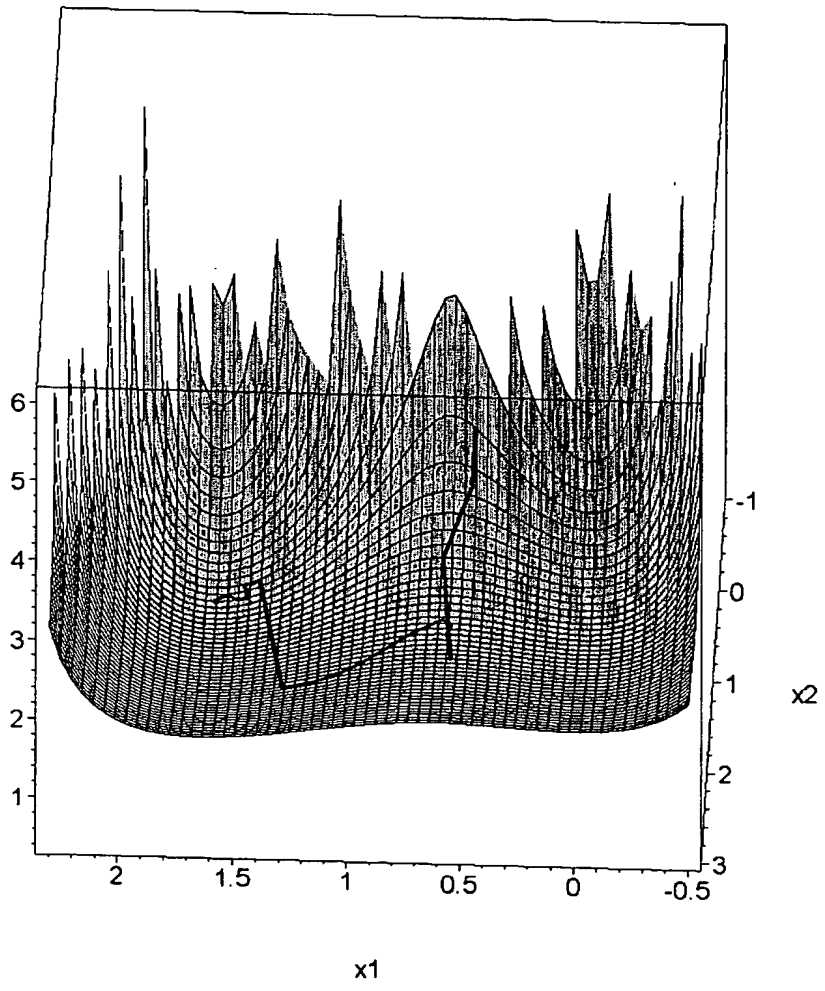


Figure 1B

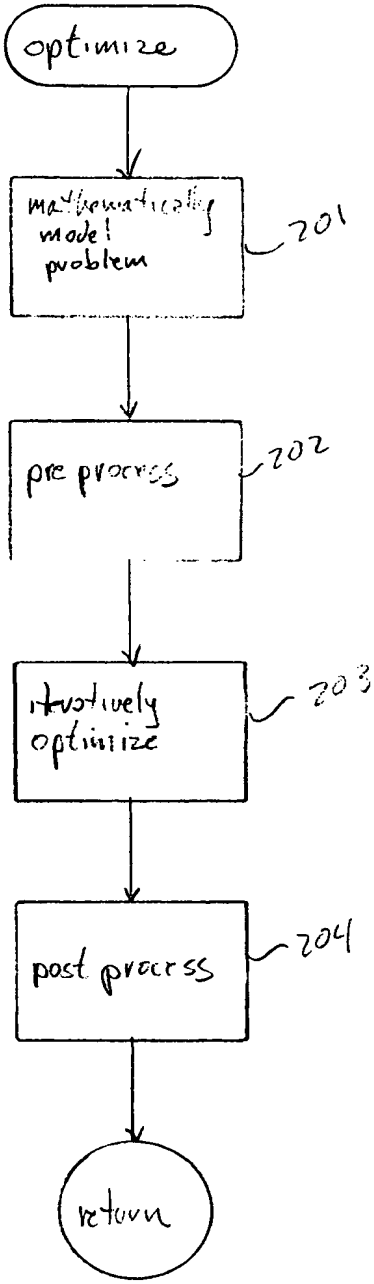

optimize
mathematically model problem
201
pre process
202
intuitively optimize
203
post process
204
return

Figure 2

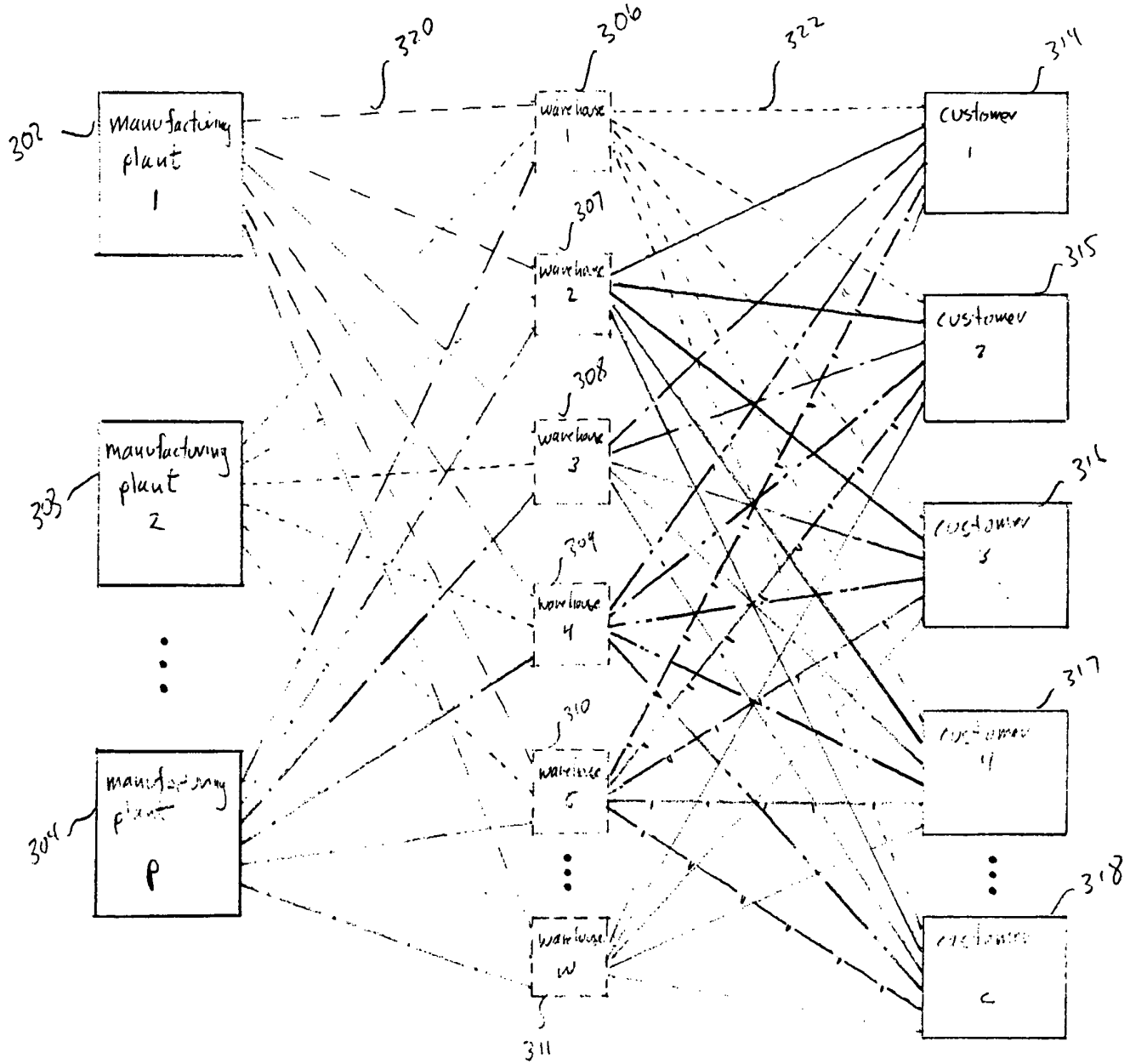

320
306
322
314
302
manufacturing plant 1
warehouse 1
customer 1
307
warehouse 2
315
customer 2
303
manufacturing plant 2
308
warehouse 3
316
customer 3
309
warehouse 4
317
customer 4
304
manufacturing plant P
310
warehouse 5
customer C
warehouse W
318
311

Figure 3

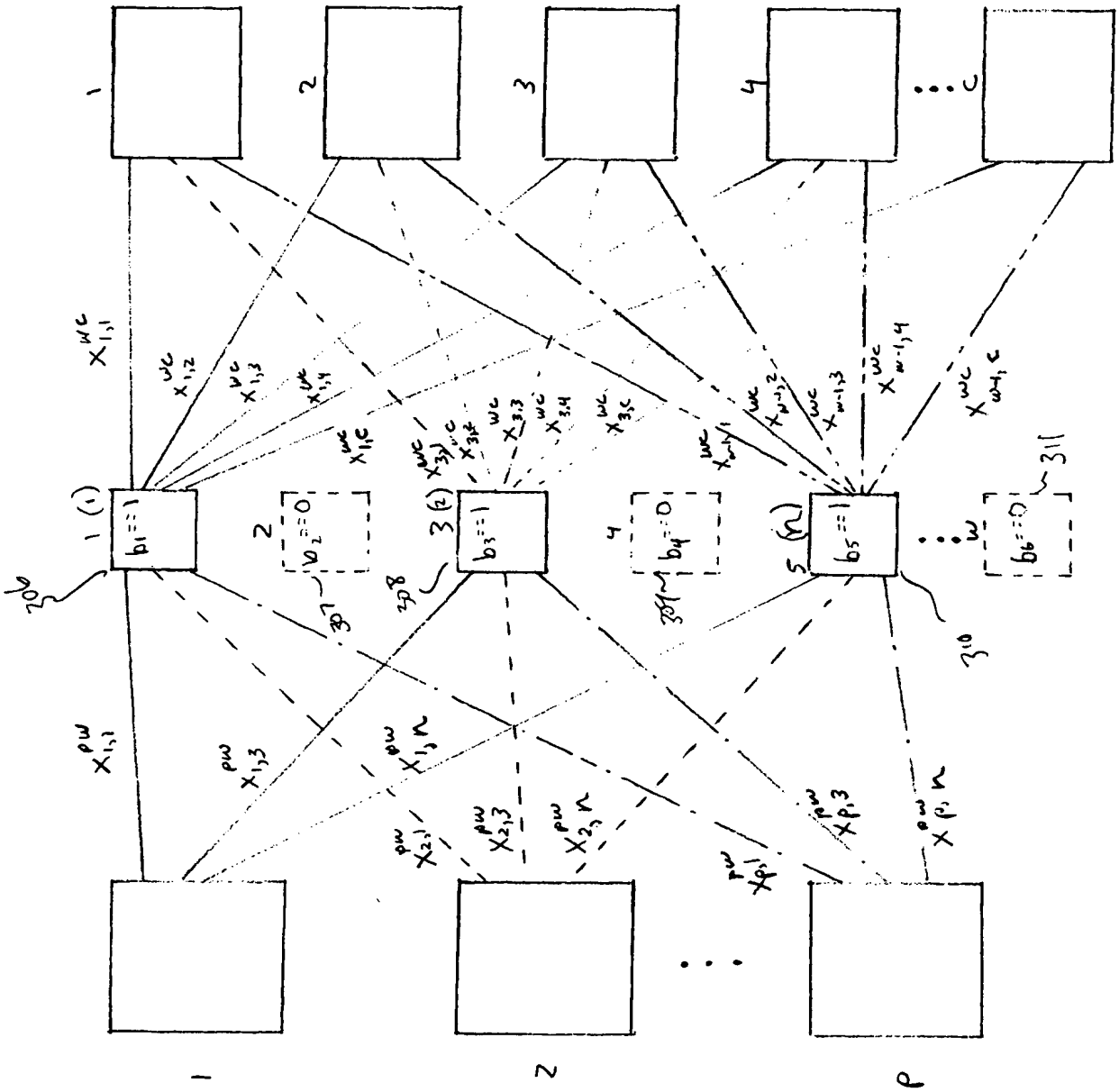

1
2
3
4
C
1 (1)
2
3 (t)
4
5 (N)
W
b1==1
b2==0
b3==1
b4==0
b5==1
b6==0
306
307
308
309
310
311
1
2
P

Figure 4

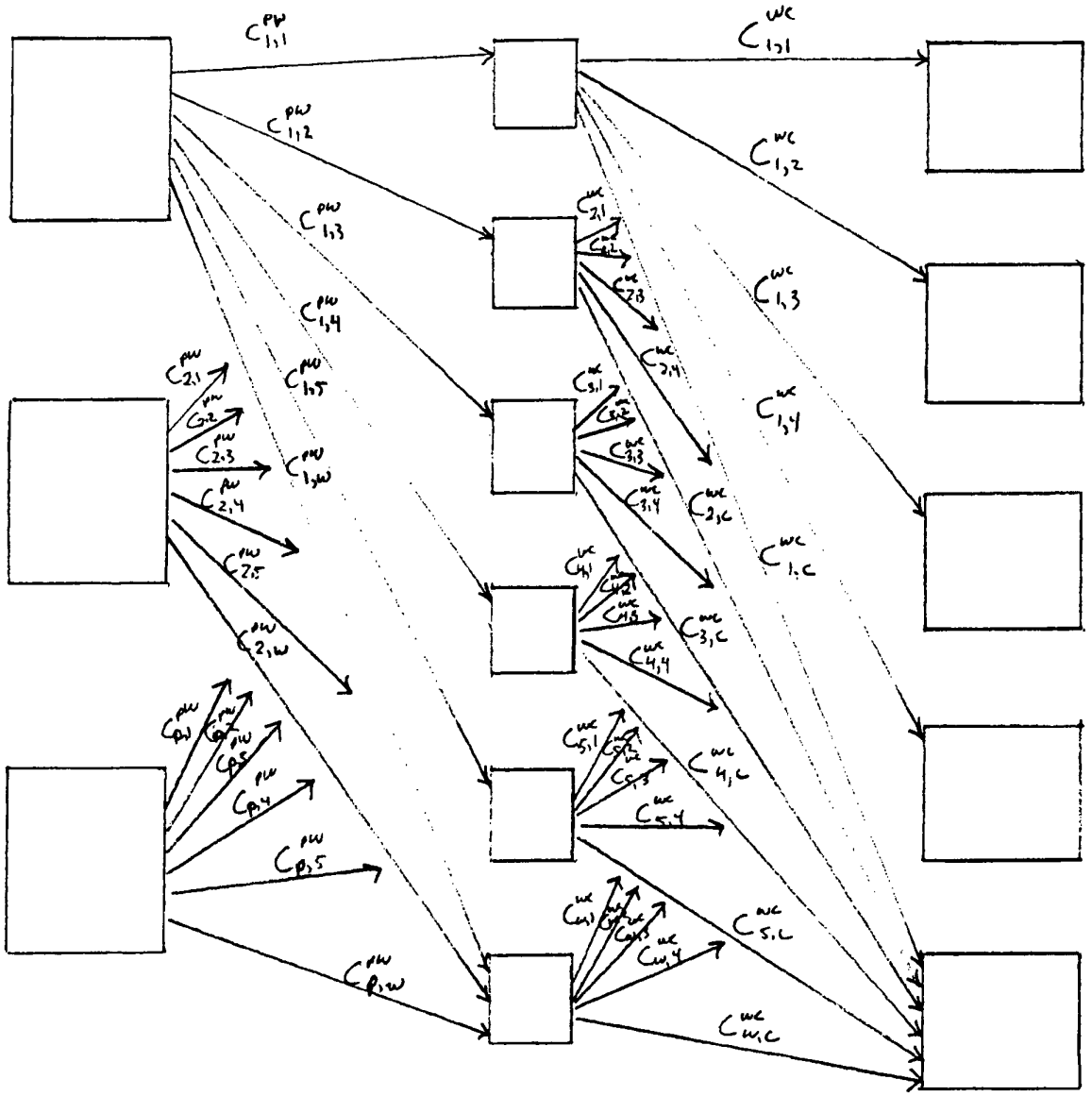

$C^{pw}_{1,1}$
$C^{pw}_{1,2}$
$C^{pw}_{1,3}$
$C^{pw}_{1,4}$
$C^{pw}_{1,5}$
$C^{pw}_{1,w}$
$C^{pw}_{2,1}$
$C^{pw}_{2,2}$
$C^{pw}_{2,3}$
$C^{pw}_{2,4}$
$C^{pw}_{2,5}$
$C^{pw}_{2,w}$
$C^{pw}_{p,1}$
$C^{pw}_{p,2}$
$C^{pw}_{p,3}$
$C^{pw}_{p,4}$
$C^{pw}_{p,5}$
$C^{pw}_{p,w}$
$C^{wc}_{1,1}$
$C^{wc}_{1,2}$
$C^{wc}_{1,3}$
$C^{wc}_{1,4}$
$C^{wc}_{1,c}$
$C^{wc}_{2,1}$
$C^{wc}_{2,2}$
$C^{wc}_{2,3}$
$C^{wc}_{2,4}$
$C^{wc}_{2,c}$
$C^{wc}_{3,1}$
$C^{wc}_{3,2}$
$C^{wc}_{3,3}$
$C^{wc}_{3,4}$
$C^{wc}_{3,c}$
$C^{wc}_{4,1}$
$C^{wc}_{4,2}$
$C^{wc}_{4,3}$
$C^{wc}_{4,4}$
$C^{wc}_{4,c}$
$C^{wc}_{5,1}$
$C^{wc}_{5,2}$
$C^{wc}_{5,3}$
$C^{wc}_{5,4}$
$C^{wc}_{5,c}$
$C^{wc}_{w,1}$
$C^{wc}_{w,2}$
$C^{wc}_{w,3}$
$C^{wc}_{w,4}$
$C^{wc}_{w,c}$

Figure 5

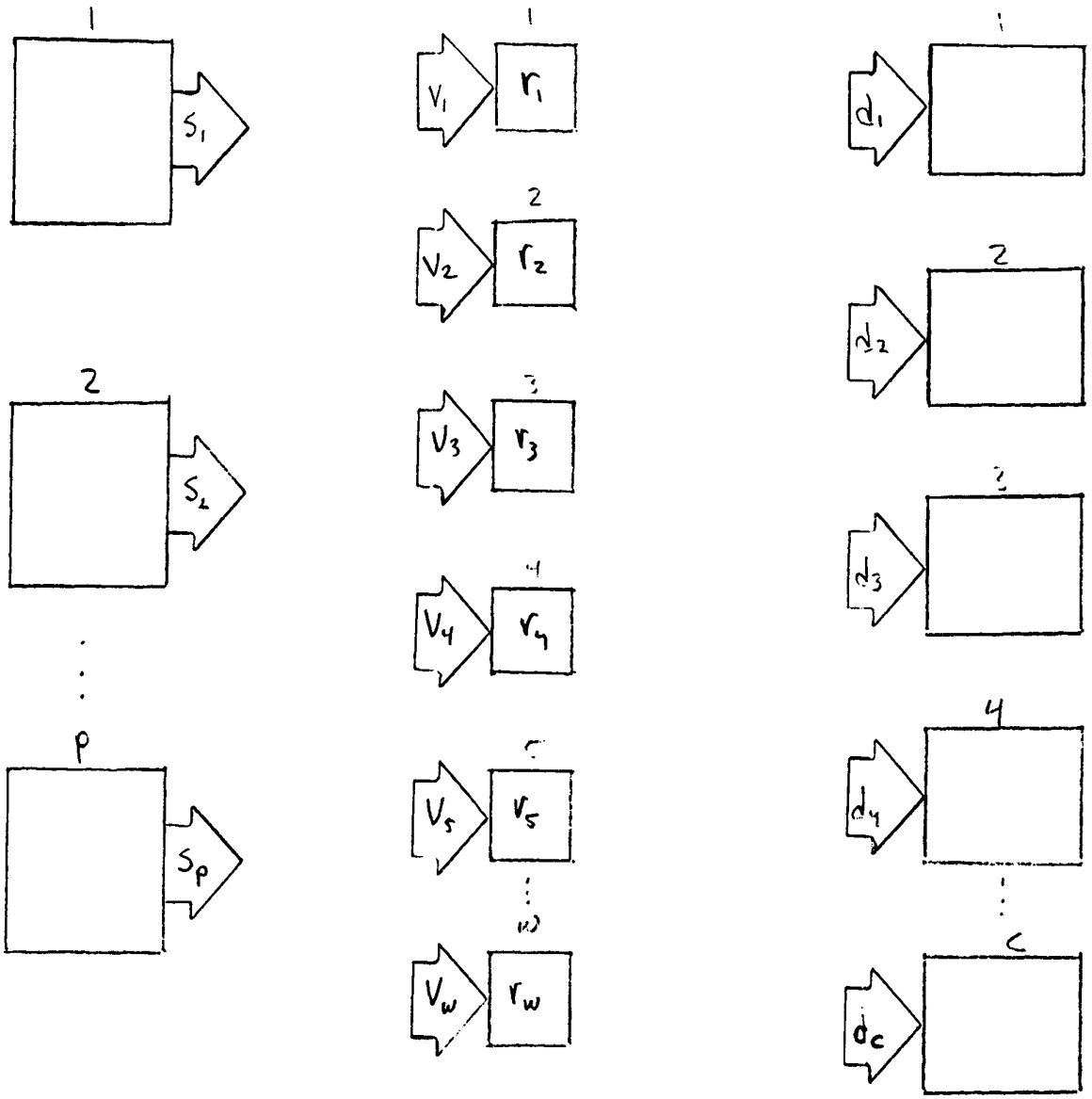

1
S_1
2
S_2
p
S_p
1
V_1
r_1
2
V_2
r_2
3
V_3
r_3
4
V_4
r_4
5
V_5
r_5
w
V_w
r_w
1
d_1
2
d_2
3
d_3
4
d_4
c
d_c

Figure 6

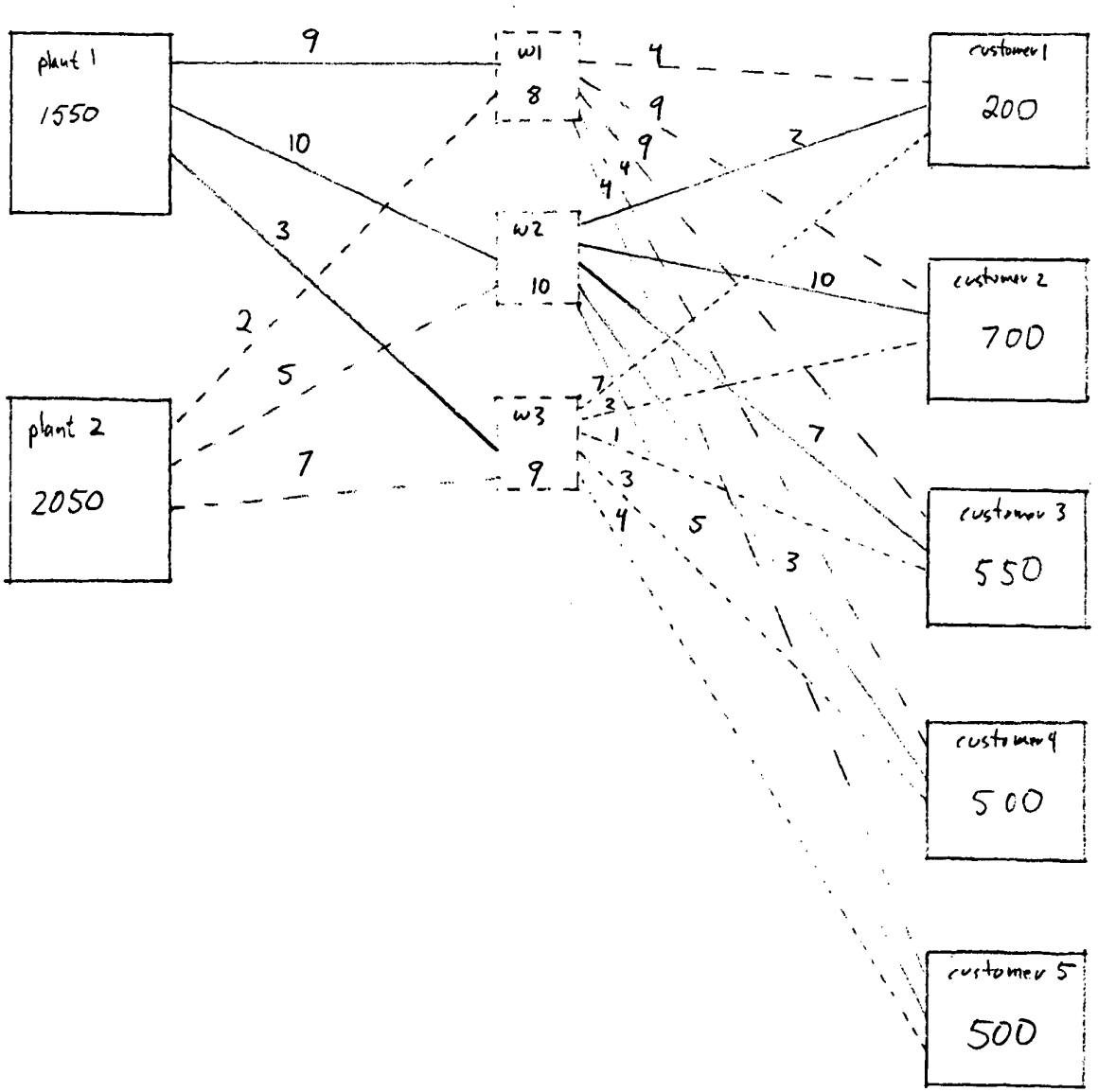

plant 1
1550
plant 2
2050
w1
8
w2
10
w3
9
customer 1
200
customer 2
700
customer 3
550
customer 4
500
customer 5
500
9
10
3
2
5
7
4
9
9
4
4
3
10
7
7
3
1
3
4
5
3

Figure 7

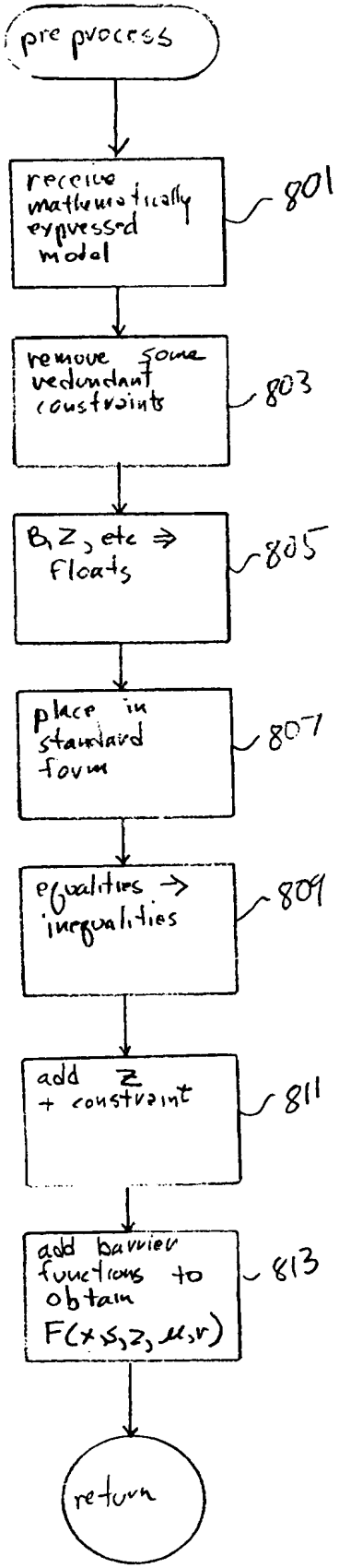

pre process
receive mathematically expressed model
801
remove some redundant constraints
803
B, Z, etc ⇒ floats
805
place in standard form
807
equalities → inequalities
809
add z + constraint
811
add barrier functions to obtain F(x, s, z, μ, r)
813
return

Figure 8

$$\underset{\mathbf{x},\mathbf{b}}{\text{minimize}} \quad C(\mathbf{x},\mathbf{b}) = \begin{pmatrix} 9*1550x_{11}^{pw} + 10*1550x_{12}^{pw} + 3*1550x_{13}^{pw} \\ +2*2050x_{21}^{pw} + 5*2050x_{22}^{pw} + 7*2050x_{23}^{pw} \\ +4*200x_{11}^{wc} + 9*700x_{12}^{wc} + 9*550x_{13}^{wc} \\ +4*500x_{14}^{wc} + 4*500x_{15}^{wc} + 2*200x_{21}^{wc} \\ +10*700x_{22}^{wc} + 7*550x_{23}^{wc} + 3*500x_{24}^{wc} \\ +5*500x_{25}^{wc} + 7*200x_{31}^{wc} + 2*700x_{32}^{wc} \\ +1*550x_{33}^{wc} + 3*500x_{34}^{wc} + 4*500x_{35}^{wc} \\ +8b_1 + 10b_2 + 9b_3 \end{pmatrix}$$

902

subject to

$$\left.\begin{aligned} x_{11}^{pw} + x_{12}^{pw} + x_{13}^{pw} &\le 1 \\ x_{21}^{pw} + x_{22}^{pw} + x_{23}^{pw} &\le 1 \end{aligned}\right\}$$ 904

$$\left.\begin{aligned} x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} &= 1 \\ x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} &= 1 \\ x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} &= 1 \\ x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} &= 1 \\ x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} &= 1 \end{aligned}\right\}$$ 906

$$\left.\begin{aligned} 1550x_{11}^{pw} + 2050x_{21}^{pw} &\ge (200x_{11}^{wc} + 700x_{12}^{wc} + 550x_{13}^{wc} + 500x_{14}^{wc} + 500x_{15}^{wc}) \\ 1550x_{12}^{pw} + 2050x_{22}^{pw} &\ge (200x_{21}^{wc} + 700x_{22}^{wc} + 550x_{23}^{wc} + 500x_{24}^{wc} + 500x_{25}^{wc}) \\ 1550x_{13}^{pw} + 2050x_{23}^{pw} &\ge (200x_{31}^{wc} + 700x_{32}^{wc} + 550x_{33}^{wc} + 500x_{34}^{wc} + 500x_{35}^{wc}) \end{aligned}\right\}$$ 908

$$\left.\begin{aligned} x_{11}^{wc}, x_{12}^{wc}, x_{13}^{wc}, x_{14}^{wc}, x_{15}^{wc}, &\le b_1 \\ x_{21}^{wc}, x_{22}^{wc}, x_{23}^{wc}, x_{24}^{wc}, x_{25}^{wc}, &\le b_2 \\ x_{31}^{wc}, x_{32}^{wc}, x_{33}^{wc}, x_{34}^{wc}, x_{35}^{wc}, &\le b_3 \end{aligned}\right\}$$ 910

$$b_1 + b_2 + b_3 \le 2$$ 912

914 — $x_{ij}^{pw}, x_{jk}^{wc} \ge 0$

916 — $b_1, b_2, b_3 \in \{0,1\}$ b's are Boolean

Figure 9

$b_i\,(1 - b_i) = 0$ and $0 \le b_i \le 1$.

$$\min_{\mathbf{x},\mathbf{b}} \quad C(\mathbf{x},\mathbf{b}) = \begin{pmatrix} 13950x_{11}^{pw} + 15500x_{12}^{pw} + 4650x_{13}^{pw} \\ +4100x_{21}^{pw} + 10250x_{22}^{pw} + 14350x_{23}^{pw} \\ +800x_{11}^{wc} + 6300x_{12}^{wc} + 4950x_{13}^{wc} \\ +2000x_{14}^{wc} + 2000x_{15}^{wc} + 400x_{21}^{wc} \\ +7000x_{22}^{wc} + 3850x_{23}^{wc} + 1500x_{24}^{wc} \\ +2500x_{25}^{wc} + 1400x_{31}^{wc} + 1400x_{32}^{wc} \\ +550x_{33}^{wc} + 1500x_{34}^{wc} + 2000x_{35}^{wc} \\ +8b_1 + 10b_2 + 9b_3 \end{pmatrix}$$

s.t.

$$-x_{11}^{pw} - x_{12}^{pw} - x_{13}^{pw} + 1 \ge 0$$
$$-x_{21}^{pw} - x_{22}^{pw} - x_{23}^{pw} + 1 \ge 0$$
$$1550x_{11}^{pw} + 2050x_{21}^{pw} - (200x_{11}^{wc} + 700x_{12}^{wc} + 550x_{13}^{wc} + 500x_{14}^{wc} + 500x_{15}^{wc}) \ge 0$$
$$1550x_{12}^{pw} + 2050x_{22}^{pw} - (200x_{21}^{wc} + 700x_{22}^{wc} + 550x_{23}^{wc} + 500x_{24}^{wc} + 500x_{25}^{wc}) \ge 0$$
$$1550x_{13}^{pw} + 2050x_{23}^{pw} - (200x_{31}^{wc} + 700x_{32}^{wc} + 550x_{33}^{wc} + 500x_{34}^{wc} + 500x_{35}^{wc}) \ge 0$$
$$b_1 - x_{11}^{wc} \ge 0$$
$$b_1 - x_{12}^{wc} \ge 0$$
$$b_1 - x_{13}^{wc} \ge 0$$
$$b_1 - x_{14}^{wc} \ge 0$$
$$b_1 - x_{15}^{wc} \ge 0$$
$$b_2 - x_{21}^{wc} \ge 0$$
$$b_2 - x_{22}^{wc} \ge 0$$
$$b_2 - x_{23}^{wc} \ge 0$$
$$b_2 - x_{24}^{wc} \ge 0$$
$$b_2 - x_{25}^{wc} \ge 0$$
$$b_3 - x_{31}^{wc} \ge 0$$
$$b_3 - x_{32}^{wc} \ge 0$$
$$b_3 - x_{33}^{wc} \ge 0$$
$$b_3 - x_{34}^{wc} \ge 0$$
$$b_3 - x_{35}^{wc} \ge 0$$
$$-b_1 - b_2 - b_3 + 2 \ge 0$$
$$x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1 = 0$$
$$x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1 = 0$$
$$x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1 = 0$$
$$x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1 = 0$$
$$x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1 = 0$$
$$b_1\,(1 - b_1) = 0$$
$$b_2\,(1 - b_2) = 0$$
$$b_3\,(1 - b_3) = 0$$
$$0 \le b_1 \le 1$$
$$0 \le b_2 \le 1$$
$$0 \le b_3 \le 1$$
$$x_{ij}^{pw},\, x_{jk}^{wc} \ge 0$$

Figure 10

$$\min_{\mathbf{x},\mathbf{b}} \quad C(\mathbf{x},\mathbf{b}) = \begin{pmatrix} 13950x_{11}^{pw} + 15500x_{12}^{pw} + 4650x_{13}^{pw} \\ +4100x_{21}^{pw} + 10250x_{22}^{pw} + 14350x_{23}^{pw} \\ +800x_{11}^{wc} + 6300x_{12}^{wc} + 4950x_{13}^{wc} \\ +2000x_{14}^{wc} + 2000x_{15}^{wc} + 400x_{21}^{wc} \\ +7000x_{22}^{wc} + 3850x_{23}^{wc} + 1500x_{24}^{wc} \\ +2500x_{25}^{wc} + 1400x_{31}^{wc} + 1400x_{32}^{wc} \\ +550x_{33}^{wc} + 1500x_{34}^{wc} + 2000x_{35}^{wc} \\ +8b_1 + 10b_2 + 9b_3 \end{pmatrix}$$

s.t.

$$\begin{aligned}
&-x_{11}^{pw} - x_{12}^{pw} - x_{13}^{pw} + 1 \geq 0 \\
&-x_{21}^{pw} - x_{22}^{pw} - x_{23}^{pw} + 1 \geq 0 \\
&1550x_{11}^{pw} + 2050x_{21}^{pw} - (200x_{11}^{wc} + 700x_{12}^{wc} + 550x_{13}^{wc} + 500x_{14}^{wc} + 500x_{15}^{wc}) \geq 0 \\
&1550x_{12}^{pw} + 2050x_{22}^{pw} - (200x_{21}^{wc} + 700x_{22}^{wc} + 550x_{23}^{wc} + 500x_{24}^{wc} + 500x_{25}^{wc}) \geq 0 \\
&1550x_{13}^{pw} + 2050x_{23}^{pw} - (200x_{31}^{wc} + 700x_{32}^{wc} + 550x_{33}^{wc} + 500x_{34}^{wc} + 500x_{35}^{wc}) \geq 0 \\
&b_1 - x_{11}^{wc} \geq 0 \\
&b_1 - x_{12}^{wc} \geq 0 \\
&b_1 - x_{13}^{wc} \geq 0 \\
&b_1 - x_{14}^{wc} \geq 0 \\
&b_1 - x_{15}^{wc} \geq 0 \\
&b_2 - x_{21}^{wc} \geq 0 \\
&b_2 - x_{22}^{wc} \geq 0 \\
&b_2 - x_{23}^{wc} \geq 0 \\
&b_2 - x_{24}^{wc} \geq 0 \\
&b_2 - x_{25}^{wc} \geq 0 \\
&b_3 - x_{31}^{wc} \geq 0 \\
&b_3 - x_{32}^{wc} \geq 0 \\
&b_3 - x_{33}^{wc} \geq 0 \\
&b_3 - x_{34}^{wc} \geq 0 \\
&b_3 - x_{35}^{wc} \geq 0 \\
&-b_1 - b_2 - b_3 + 2 \geq 0 \\
&x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1 = 0 \\
&x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1 = 0 \\
&x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1 = 0 \\
&x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1 = 0 \\
&x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1 = 0 \\
&x_{ij}^{pw}, x_{jk}^{wc} \geq 0 \\
&b_1, b_2, b_3 \in \{0, 1\}
\end{aligned}$$

Figure 11

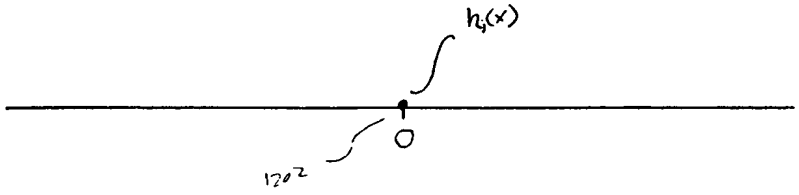


Figure 12A

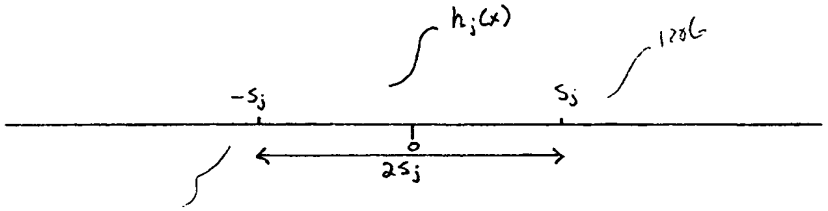


Figure 12B

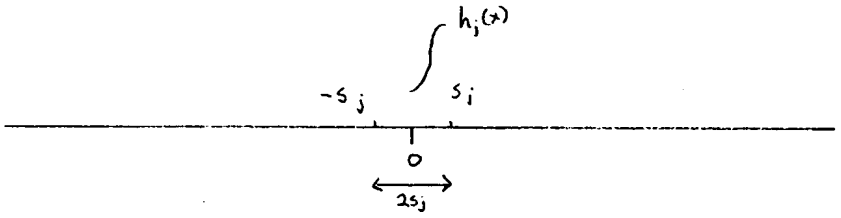


Figure 12C

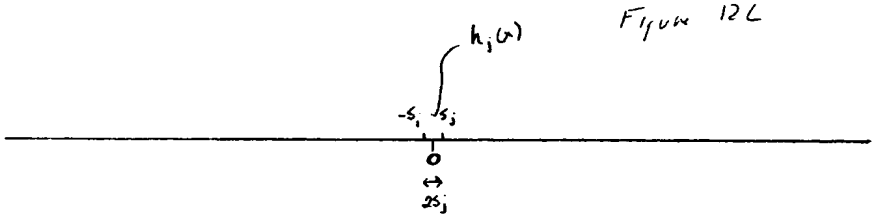


Figure 12D

$$\min_{\mathbf{x},\mathbf{b},\mathbf{s}} \quad \bar{C}(\mathbf{x},\mathbf{b},\mathbf{s},\mathbf{r}) = \begin{pmatrix} 13950x_{11}^{pw} + 15500x_{12}^{pw} + 4650x_{13}^{pw} + 4100x_{21}^{pw} + 10250x_{22}^{pw} \\ +14350x_{23}^{pw} + 800x_{11}^{wc} + 6300x_{12}^{wc} + 4950x_{13}^{wc} + 2000x_{14}^{wc} \\ +2000x_{15}^{wc} + 400x_{21}^{wc} + 7000x_{22}^{wc} + 3850x_{23}^{wc} + 1500x_{24}^{wc} \\ +2500x_{25}^{wc} + 1400x_{31}^{wc} + 1400x_{32}^{wc} + 550x_{33}^{wc} + 1500x_{34}^{wc} \\ +2000x_{35}^{wc} + 8b_1 + 10b_2 + 9b_3 + r_1s_1 + r_2s_2 + r_3s_3 \\ +r_4s_4 + r_5s_5 + r_6s_6 + r_7s_7 + r_8s_8 \end{pmatrix}$$

s.t.

$$\begin{aligned}
&-x_{11}^{pw} - x_{12}^{pw} - x_{13}^{pw} + 1 \geq 0 \\
&-x_{21}^{pw} - x_{22}^{pw} - x_{23}^{pw} + 1 \geq 0 \\
&1550x_{11}^{pw} + 2050x_{21}^{pw} - (200x_{11}^{wc} + 700x_{12}^{wc} + 550x_{13}^{wc} + 500x_{14}^{wc} + 500x_{15}^{wc}) \geq 0 \\
&1550x_{12}^{pw} + 2050x_{22}^{pw} - (200x_{21}^{wc} + 700x_{22}^{wc} + 550x_{23}^{wc} + 500x_{24}^{wc} + 500x_{25}^{wc}) \geq 0 \\
&1550x_{13}^{pw} + 2050x_{23}^{pw} - (200x_{31}^{wc} + 700x_{32}^{wc} + 550x_{33}^{wc} + 500x_{34}^{wc} + 500x_{35}^{wc}) \geq 0 \\
&b_1 - x_{11}^{wc} \geq 0 \\
&b_1 - x_{12}^{wc} \geq 0 \\
&b_1 - x_{13}^{wc} \geq 0 \\
&b_1 - x_{14}^{wc} \geq 0 \\
&b_1 - x_{15}^{wc} \geq 0 \\
&b_2 - x_{21}^{wc} \geq 0 \\
&b_2 - x_{22}^{wc} \geq 0 \\
&b_2 - x_{23}^{wc} \geq 0 \\
&b_2 - x_{24}^{wc} \geq 0 \\
&b_2 - x_{25}^{wc} \geq 0 \\
&b_3 - x_{31}^{wc} \geq 0 \\
&b_3 - x_{32}^{wc} \geq 0 \\
&b_3 - x_{33}^{wc} \geq 0 \\
&b_3 - x_{34}^{wc} \geq 0 \\
&b_3 - x_{35}^{wc} \geq 0 \\
&-b_1 - b_2 - b_3 + 2 \geq 0 \\
&s_1 + x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1 \geq 0 \\
&s_2 + x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1 \geq 0 \\
&s_3 + x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1 \geq 0 \\
&s_4 + x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1 \geq 0 \\
&s_5 + x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1 \geq 0 \\
&s_1 - (x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1) \geq 0 \\
&s_2 - (x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1) \geq 0 \\
&s_3 - (x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1) \geq 0 \\
&s_4 - (x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1) \geq 0 \\
&s_5 - (x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1) \geq 0 \\
&s_6 - b_1(1 - b_1) \geq 0 \\
&s_7 - b_2(1 - b_2) \geq 0 \\
&s_8 - b_3(1 - b_3) \geq 0 \\
&b_1 \geq 0, b_2 \geq 0, b_3 \geq 0 \\
&1 - b_1 \geq 0, 1 - b_2 \geq 0, 1 - b_3 \geq 0 \\
&x_{ij}^{pw}, x_{jk}^{wc}, s_i \geq 0
\end{aligned}$$

Figure 13

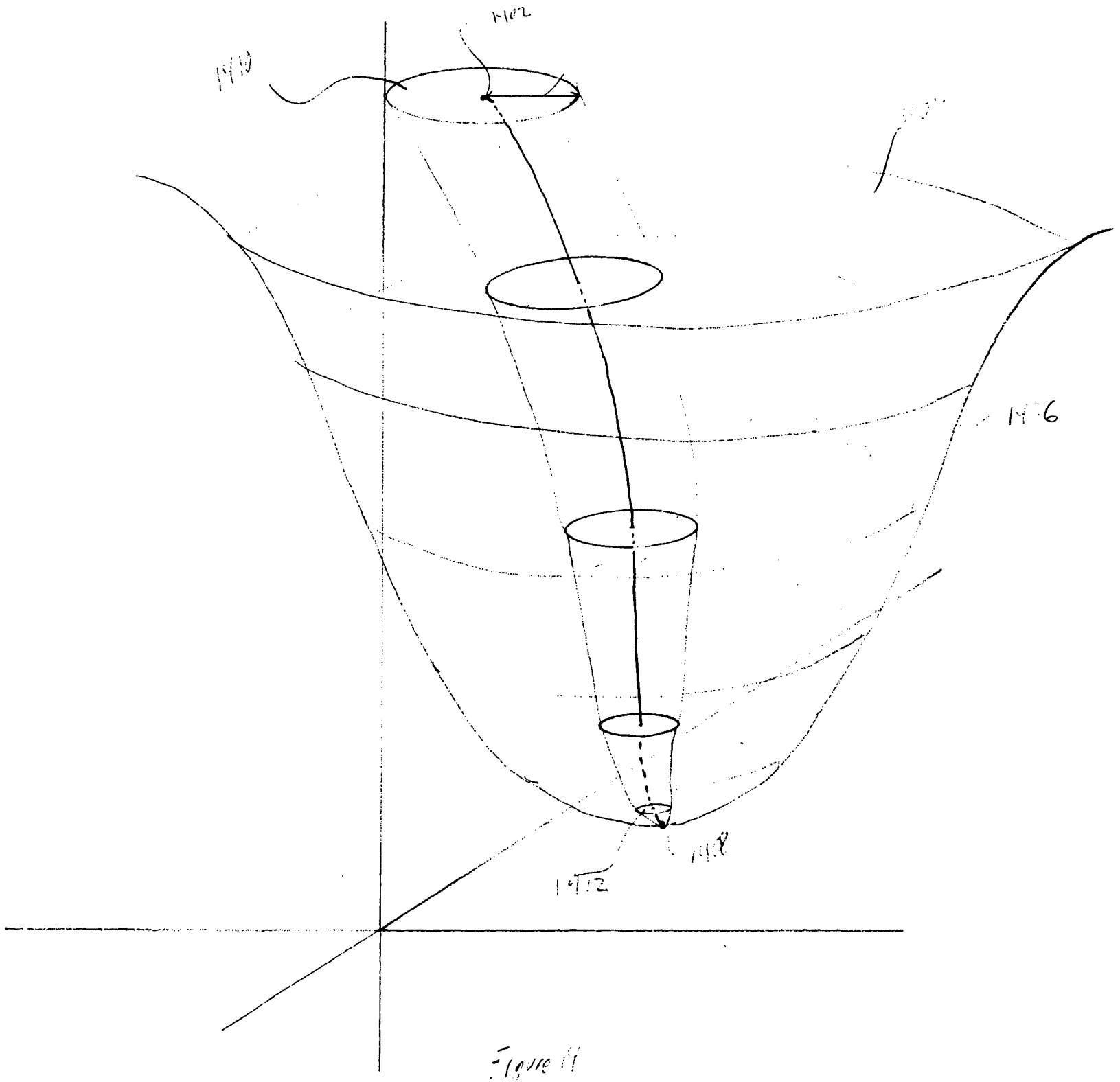


Figure 11

$$
\begin{aligned}
\min_{\mathbf{x},\mathbf{b},\mathbf{s},z} \quad & z \\
\text{s.t.} \quad & \\
& -x_{11}^{pw} - x_{12}^{pw} - x_{13}^{pw} + 1 \geq 0 \\
& -x_{21}^{pw} - x_{22}^{pw} - x_{23}^{pw} + 1 \geq 0 \\
& 1550x_{11}^{pw} + 2050x_{21}^{pw} - (200x_{11}^{wc} + 700x_{12}^{wc} + 550x_{13}^{wc} + 500x_{14}^{wc} + 500x_{15}^{wc}) \geq 0 \\
& 1550x_{12}^{pw} + 2050x_{22}^{pw} - (200x_{21}^{wc} + 700x_{22}^{wc} + 550x_{23}^{wc} + 500x_{24}^{wc} + 500x_{25}^{wc}) \geq 0 \\
& 1550x_{13}^{pw} + 2050x_{23}^{pw} - (200x_{31}^{wc} + 700x_{32}^{wc} + 550x_{33}^{wc} + 500x_{34}^{wc} + 500x_{35}^{wc}) \geq 0 \\
& b_1 - x_{11}^{wc} \geq 0 \\
& b_1 - x_{12}^{wc} \geq 0 \\
& b_1 - x_{13}^{wc} \geq 0 \\
& b_1 - x_{14}^{wc} \geq 0 \\
& b_1 - x_{15}^{wc} \geq 0 \\
& b_2 - x_{21}^{wc} \geq 0 \\
& b_2 - x_{22}^{wc} \geq 0 \\
& b_2 - x_{23}^{wc} \geq 0 \\
& b_2 - x_{24}^{wc} \geq 0 \\
& b_2 - x_{25}^{wc} \geq 0 \\
& b_3 - x_{31}^{wc} \geq 0 \\
& b_3 - x_{32}^{wc} \geq 0 \\
& b_3 - x_{33}^{wc} \geq 0 \\
& b_3 - x_{34}^{wc} \geq 0 \\
& b_3 - x_{35}^{wc} \geq 0 \\
& -b_1 - b_2 - b_3 + 2 \geq 0 \\
& s_1 + x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1 \geq 0 \\
& s_2 + x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1 \geq 0 \\
& s_3 + x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1 \geq 0 \\
& s_4 + x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1 \geq 0 \\
& s_5 + x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1 \geq 0 \\
& s_1 - (x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1) \geq 0 \\
& s_2 - (x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1) \geq 0 \\
& s_3 - (x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1) \geq 0 \\
& s_4 - (x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1) \geq 0 \\
& s_5 - (x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1) \geq 0 \\
& s_6 - b_1 (1 - b_1) \geq 0 \\
& s_7 - b_2 (1 - b_2) \geq 0 \\
& s_8 - b_3 (1 - b_3) \geq 0 \\
& b_1 \geq 0, 1 - b_1 \geq 0 \\
& b_2 \geq 0, 1 - b_2 \geq 0 \\
& b_3 \geq 0, 1 - b_3 \geq 0 \\
& x_{ij}^{pw}, x_{jk}^{wc}, s_i \geq 0 \\
& z - \tilde{C}(\mathbf{x}, \mathbf{b}, \mathbf{s}, \mathbf{r}) \geq 0
\end{aligned}
$$

Figure 15

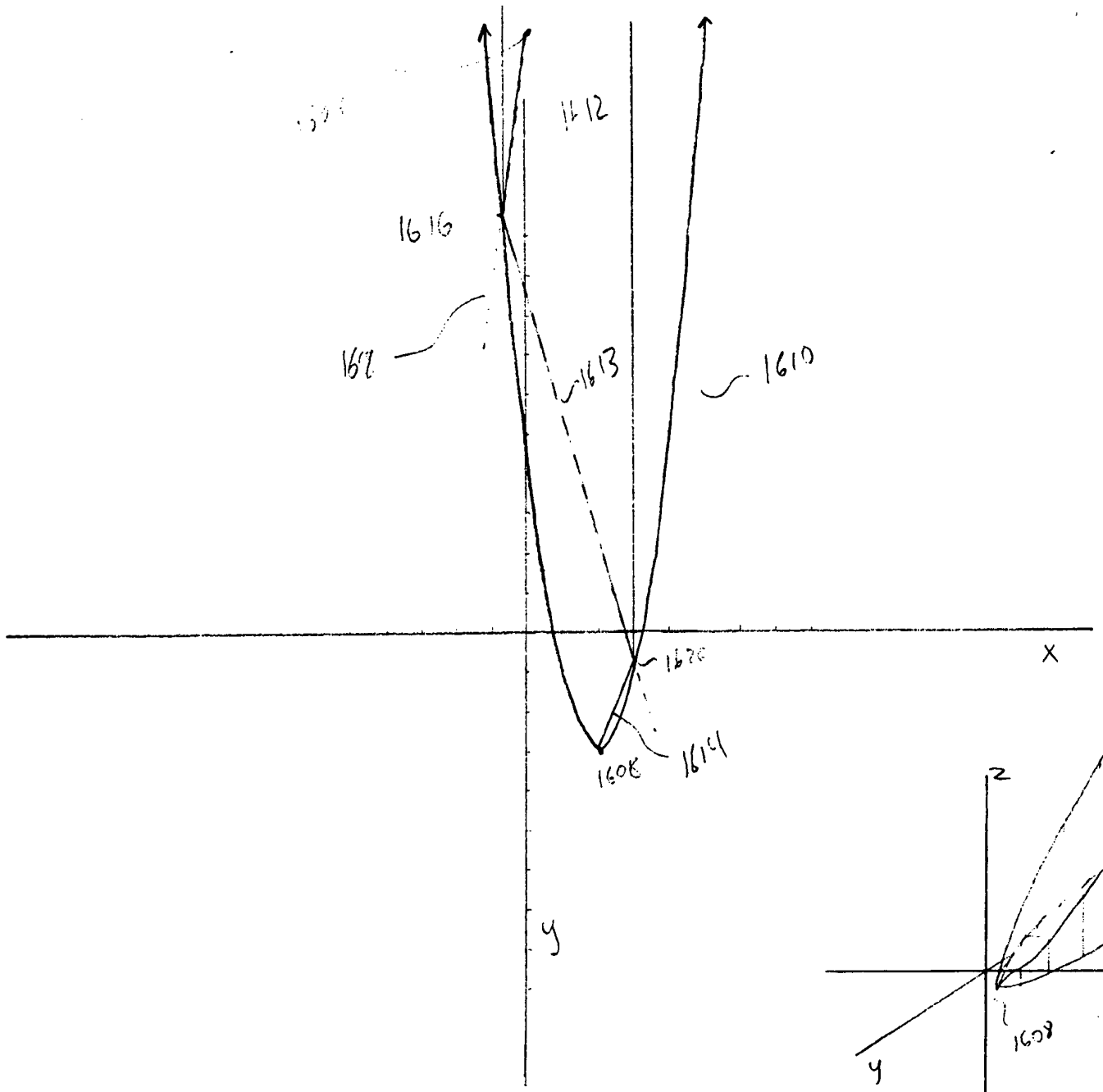


Figure 16B

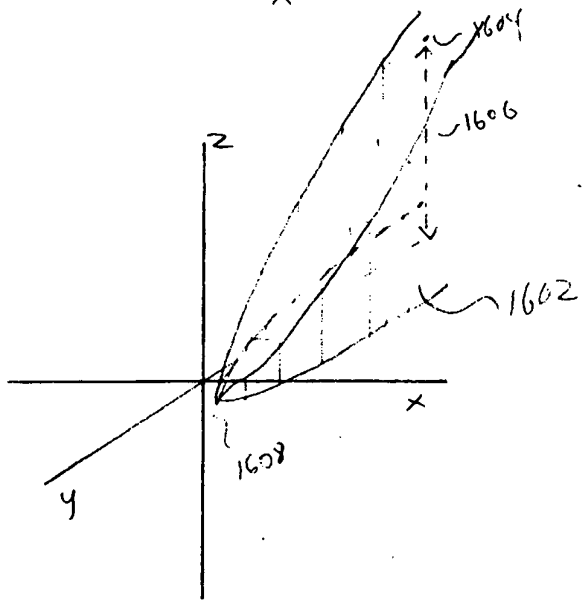


Figure 16A

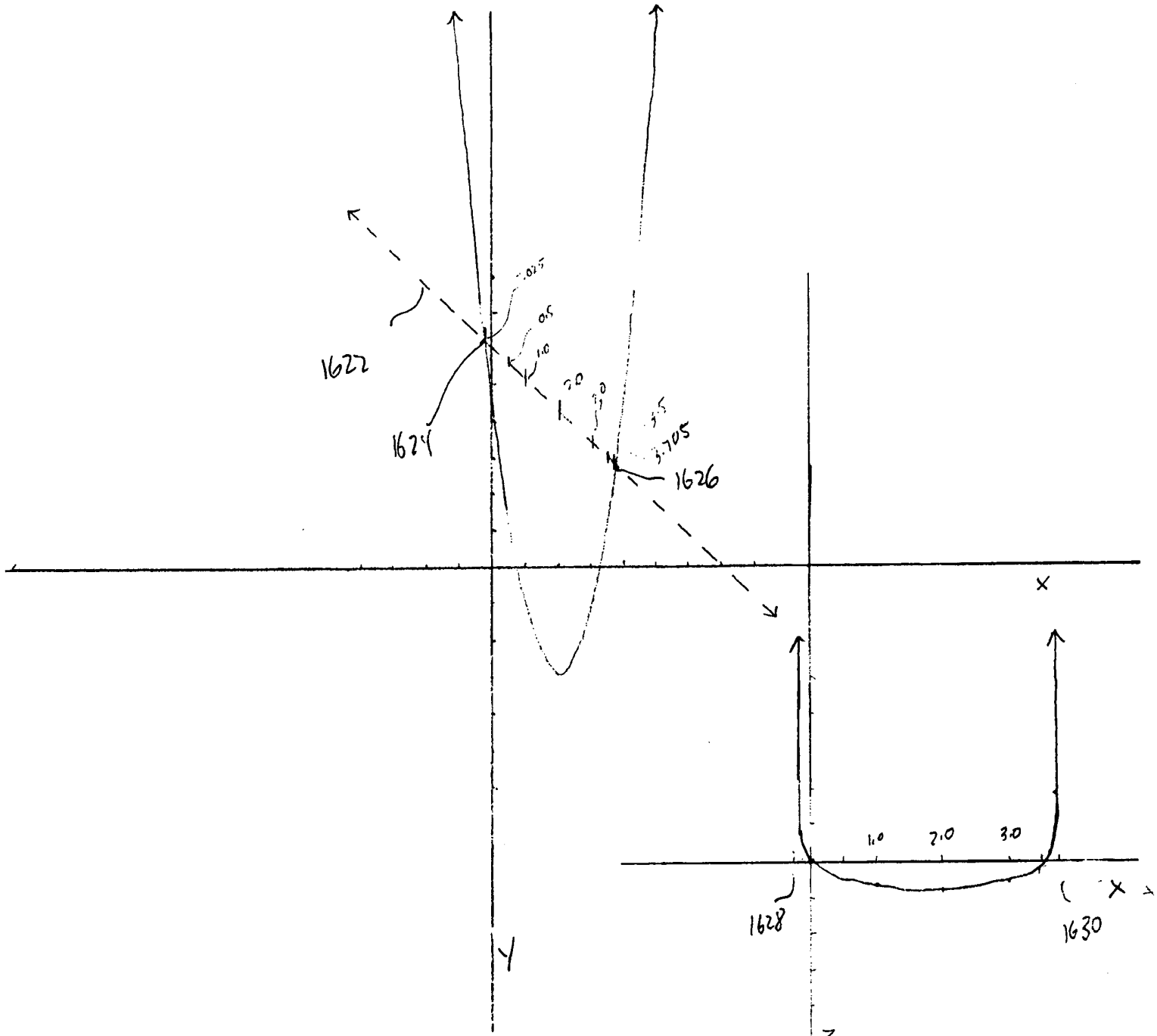


Figure 16C

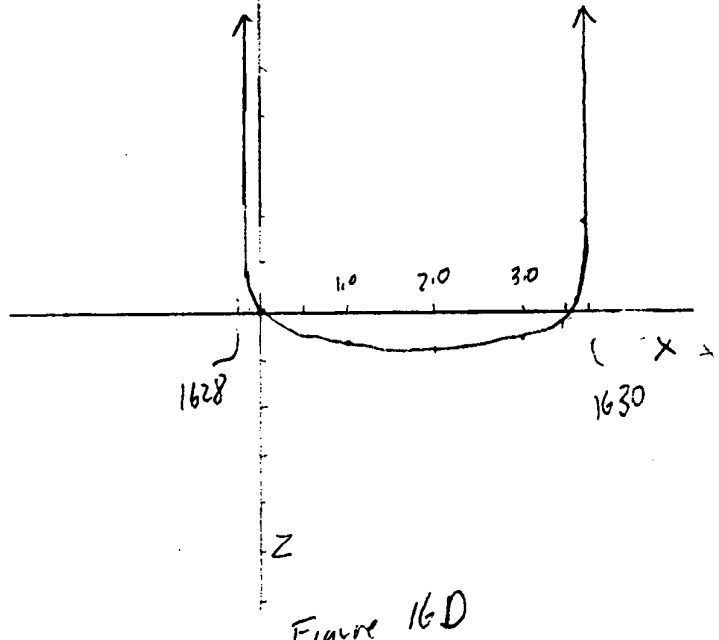


Figure 16D

$$
\begin{aligned}
\min_{\mathbf{x},\mathbf{b},\mathbf{s},z} \quad & F(\mathbf{x},\mathbf{b},\mathbf{s},\mathbf{r},z,\mathbf{u}) = \\
& z - u_1 \ln(-x_{11}^{pw} - x_{12}^{pw} - x_{13}^{pw} + 1) - u_2 \ln(-x_{21}^{pw} - x_{22}^{pw} - x_{23}^{pw} + 1) \\
& -u_3 \ln(1550x_{11}^{pw} + 2050x_{21}^{pw} - (200x_{11}^{wc} + 700x_{12}^{wc} + 550x_{13}^{wc} + 500x_{14}^{wc} + 500x_{15}^{wc})) \\
& -u_4 \ln(1550x_{12}^{pw} + 2050x_{22}^{pw} - (200x_{21}^{wc} + 700x_{22}^{wc} + 550x_{23}^{wc} + 500x_{24}^{wc} + 500x_{25}^{wc})) \\
& -u_5 \ln(1550x_{13}^{pw} + 2050x_{23}^{pw} - (200x_{31}^{wc} + 700x_{32}^{wc} + 550x_{33}^{wc} + 500x_{34}^{wc} + 500x_{35}^{wc})) \\
& -u_6 \ln(b_1 - x_{11}^{wc}) - u_7 \ln(b_1 - x_{12}^{wc}) - u_8 \ln(b_1 - x_{13}^{wc}) \\
& -u_9 \ln(b_1 - x_{14}^{wc}) - u_{10} \ln(b_1 - x_{15}^{wc}) - u_{11} \ln(b_2 - x_{21}^{wc}) \\
& -u_{12} \ln(b_2 - x_{22}^{wc}) - u_{13} \ln(b_2 - x_{23}^{wc}) - u_{14} \ln(b_2 - x_{24}^{wc}) \\
& -u_{15} \ln(b_2 - x_{25}^{wc}) - u_{16} \ln(b_3 - x_{31}^{wc}) - u_{17} \ln(b_3 - x_{32}^{wc}) \\
& -u_{18} \ln(b_3 - x_{33}^{wc}) - u_{19} \ln(b_3 - x_{34}^{wc}) - u_{20} \ln(b_3 - x_{35}^{wc}) \\
& -u_{21} \ln(-b_1 - b_2 - b_3 + 2) - u_{22} \ln(s_1 + x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1) \\
& -u_{23} \ln(s_2 + x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1) \\
& -u_{24} \ln(s_3 + x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1) \\
& -u_{25} \ln(s_4 + x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1) \\
& -u_{26} \ln(s_5 + x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1) \\
& -u_{27} \ln(s_1 - (x_{11}^{wc} + x_{21}^{wc} + x_{31}^{wc} - 1)) \\
& -u_{28} \ln(s_2 - (x_{12}^{wc} + x_{22}^{wc} + x_{32}^{wc} - 1)) \\
& -u_{29} \ln(s_3 - (x_{13}^{wc} + x_{23}^{wc} + x_{33}^{wc} - 1)) \\
& -u_{30} \ln(s_4 - (x_{14}^{wc} + x_{24}^{wc} + x_{34}^{wc} - 1)) \\
& -u_{31} \ln(s_5 - (x_{15}^{wc} + x_{25}^{wc} + x_{35}^{wc} - 1)) \\
& -u_{32} \ln(s_6 - b_1(1 - b_1)) \\
& -u_{33} \ln(s_7 - b_2(1 - b_2)) - u_{34} \ln(s_8 - b_3(1 - b_3)) \\
& -u_{35} \ln(1 - b_1) - -u_{36} \ln(1 - b_2) - u_{37} \ln(1 - b_3) \\
& -u_{38} \ln(b_1) - u_{39} \ln(b_2) - u_{40} \ln(b_3) \\
& -u_{41} \ln(x_{11}^{pw}) - u_{42} \ln(x_{12}^{pw}) - u_{43} \ln(x_{13}^{pw}) \\
& -u_{44} \ln(x_{21}^{pw}) - u_{45} \ln(x_{22}^{pw}) - u_{46} \ln(x_{23}^{pw}) \\
& -u_{47} \ln(x_{11}^{wc}) - u_{48} \ln(x_{12}^{wc}) - u_{49} \ln(x_{13}^{wc}) - u_{50} \ln(x_{14}^{wc}) \\
& -u_{51} \ln(x_{15}^{wc}) - u_{52} \ln(x_{21}^{wc}) - u_{53} \ln(x_{22}^{wc}) - u_{54} \ln(x_{23}^{wc}) \\
& -u_{55} \ln(x_{24}^{wc}) - u_{56} \ln(x_{25}^{wc}) - u_{57} \ln(x_{31}^{wc}) - u_{58} \ln(x_{32}^{wc}) \\
& -u_{59} \ln(x_{33}^{wc}) - u_{60} \ln(x_{34}^{wc}) - u_{61} \ln(x_{35}^{wc}) - u_{62} \ln(s_1) \\
& -u_{63} \ln(s_2) - u_{64} \ln(s_3) - u_{65} \ln(s_4) - u_{66} \ln(s_5) \\
& -u_{67} \ln(s_6) - u_{68} \ln(s_7) - u_{69} \ln(s_8) \\
& -u_{70} \ln\left(z - \tilde{C}(\mathbf{x},\mathbf{b},\mathbf{s})\right)
\end{aligned}
$$

Figure 17

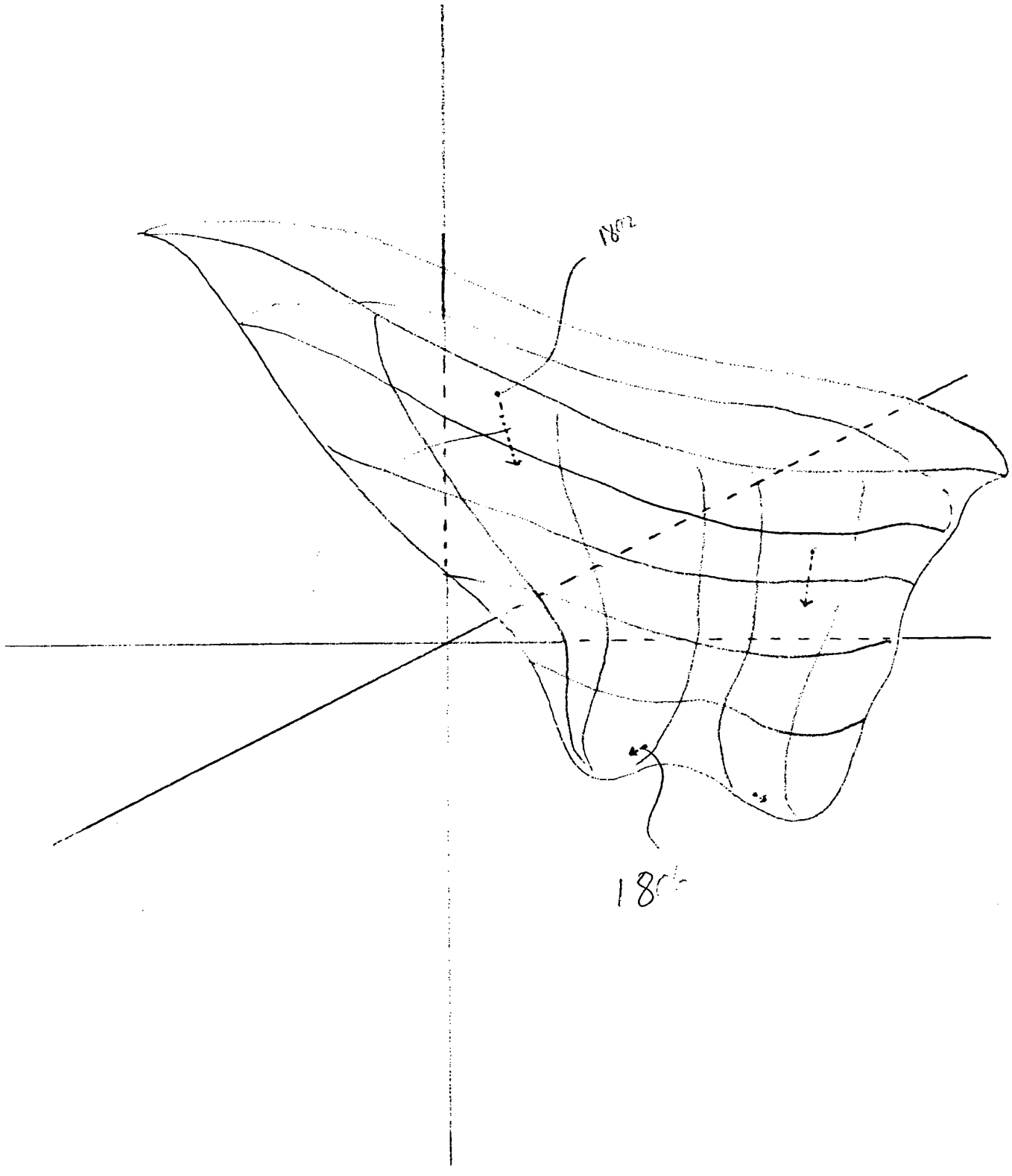


Figure 18

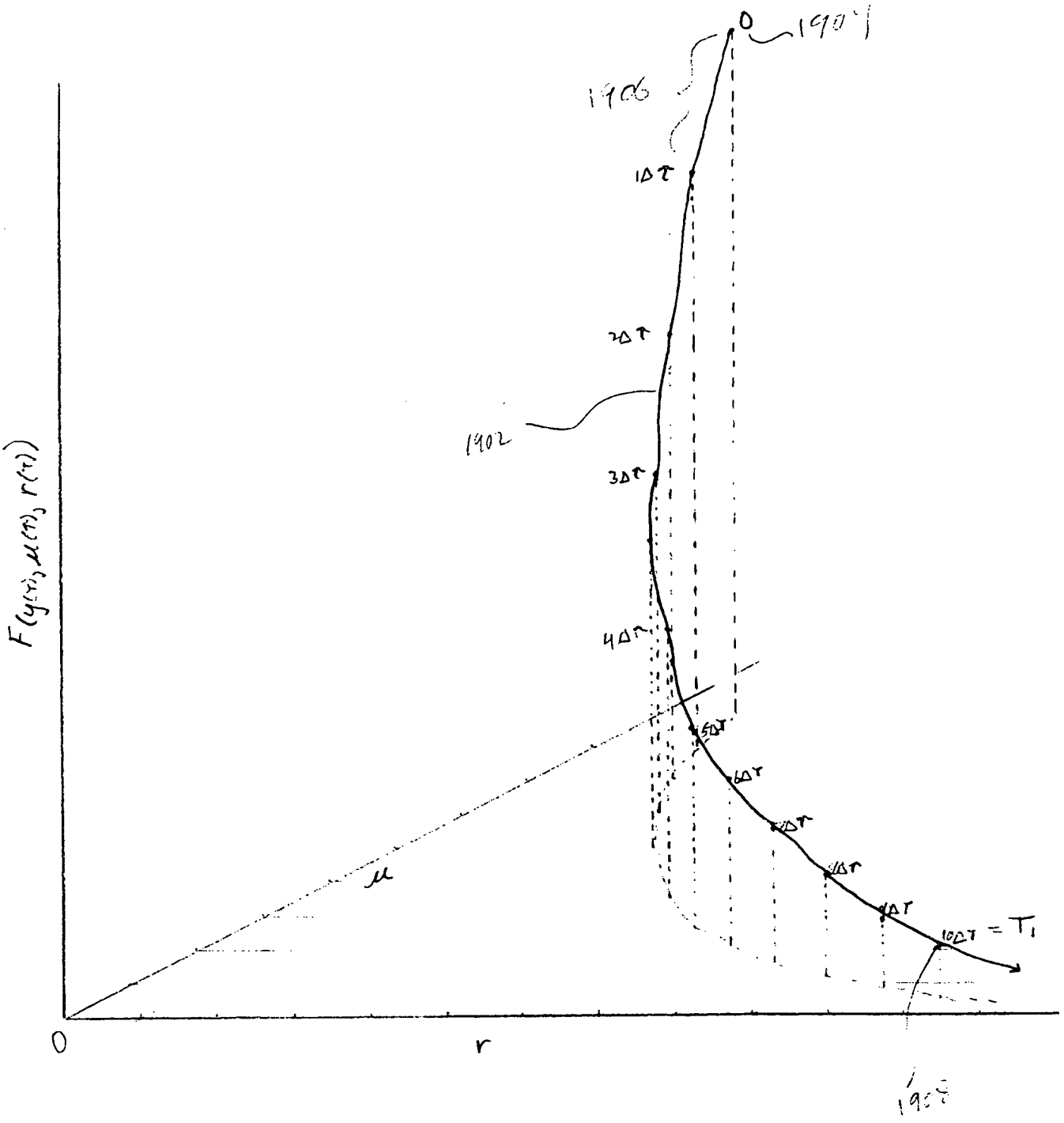

0
1907
1906
1Δτ
2Δτ
1902
3Δτ
4Δτ
5Δτ
6Δτ
7Δτ
8Δτ
9Δτ
10Δτ = T₁
μ
0
r
1909
F(y(τ), μ(τ), r(τ))

Figure 9

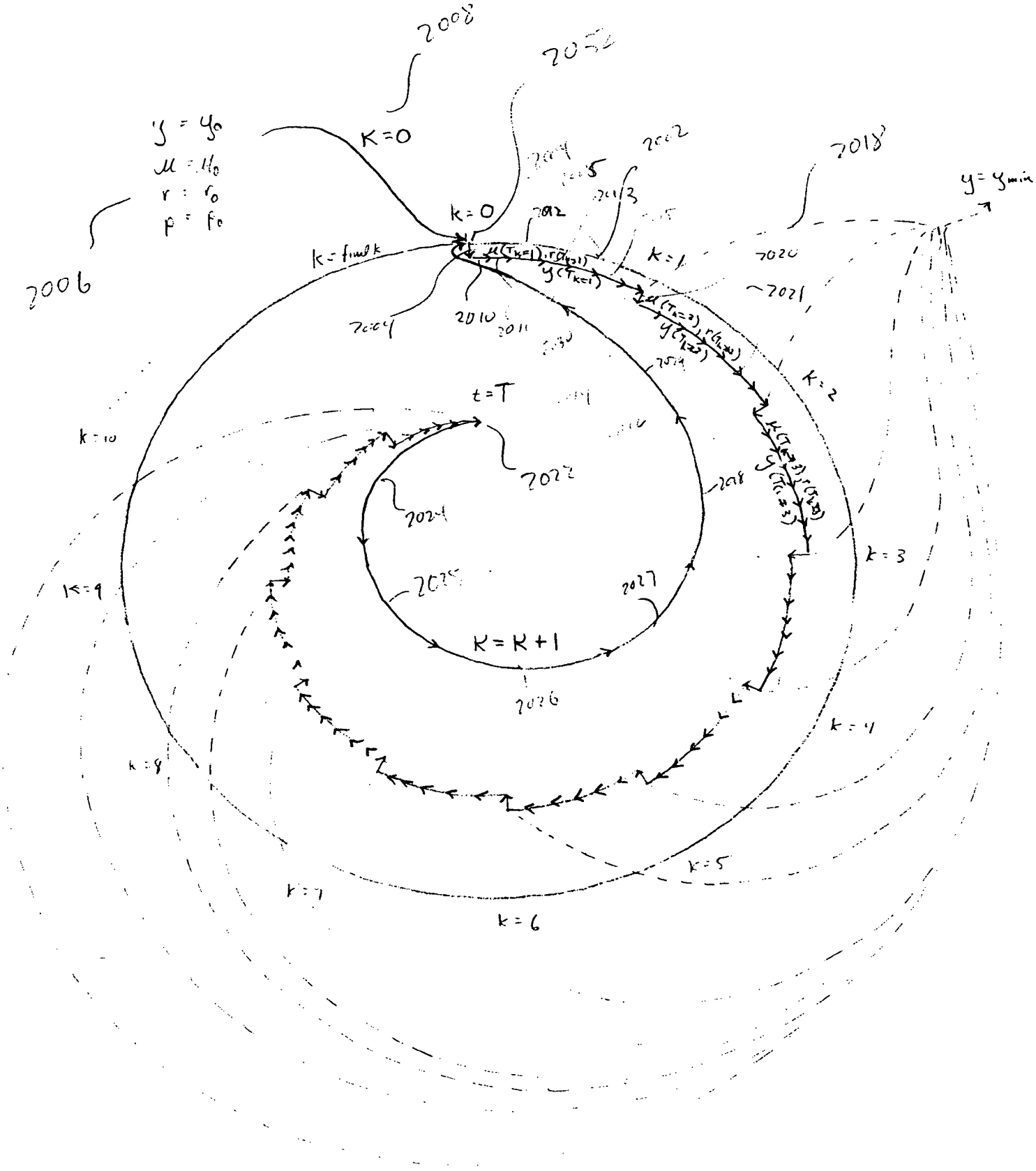

2008
2054
2006
y = y0
μ = μ0
r = r0
p = f0
K=0
k=0
2052
2004
2005
2002
2013
2018
y = ymin
2012
k = final k
k=1
2020
2021
2004
2010
2011
2030
2019
t=T
k=2
k=10
2022
2024
2018
k=3
k=9
2025
2027
K=K+1
2026
k=4
k=8
k=5
k=7
k=6

Figure 20

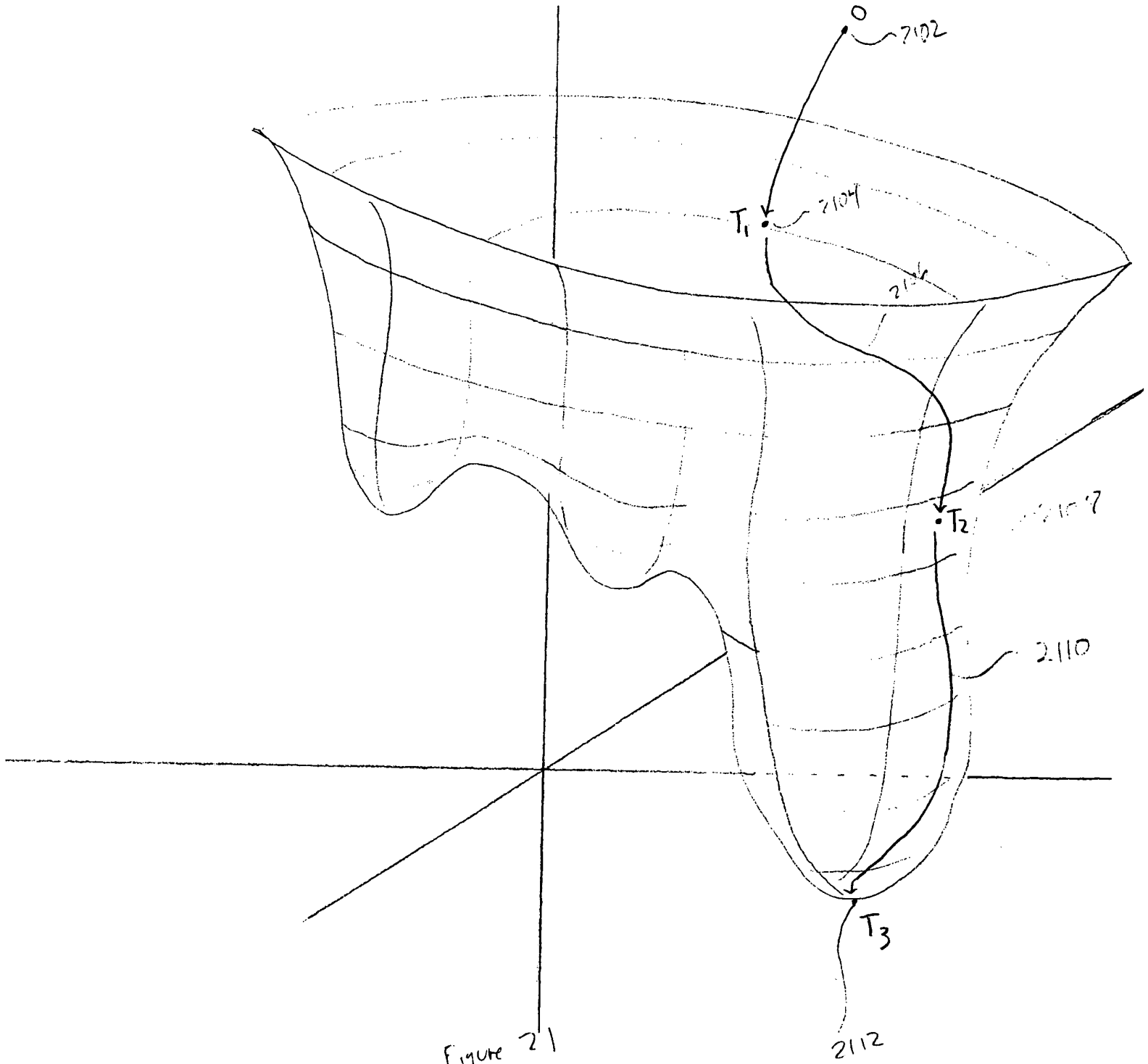


Figure 21

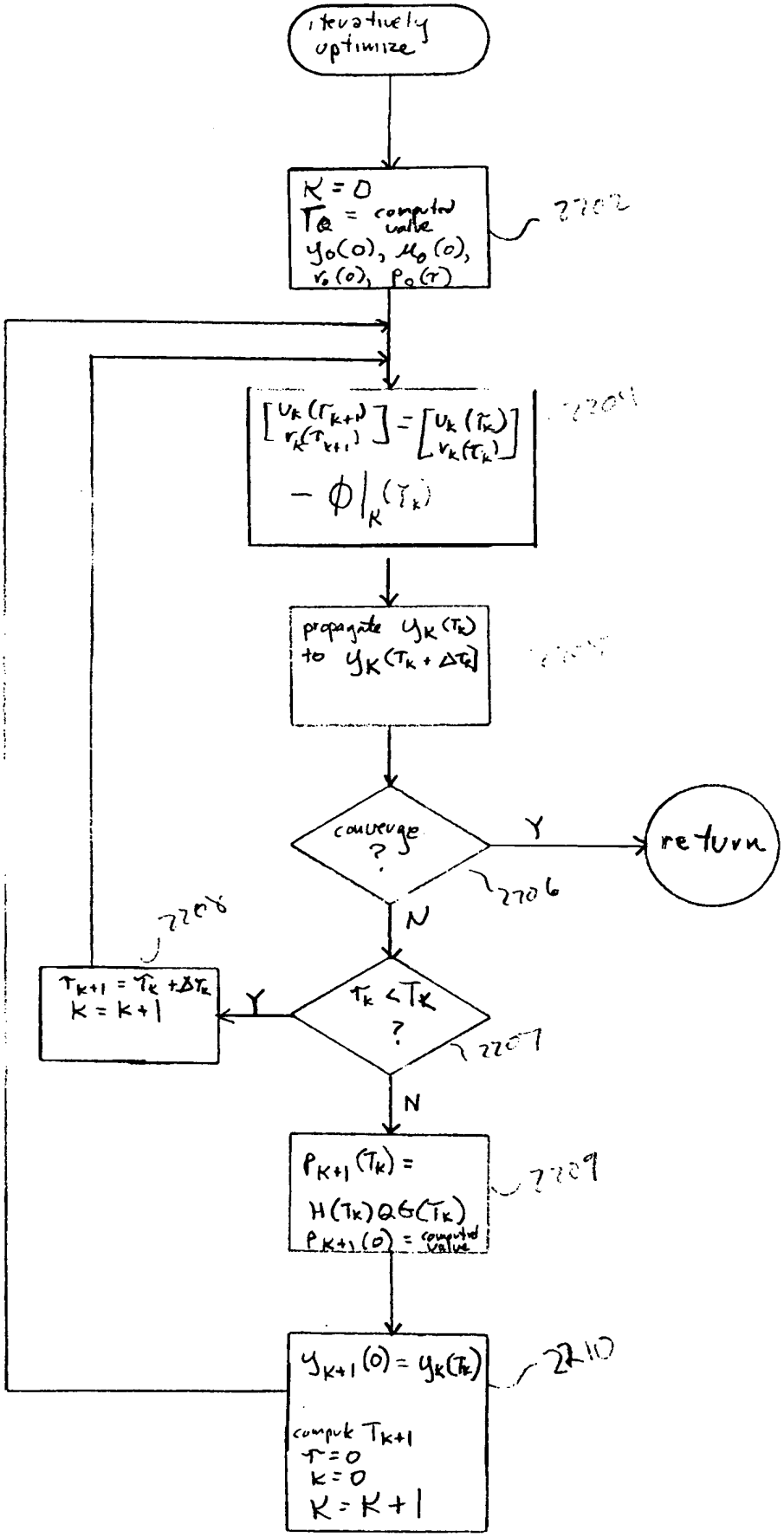

iteratively optimize
K = 0
T_0 = computer value
$y_0(0)$, $u_0(0)$, $v_0(0)$, $P_0(T)$
2202
$\begin{bmatrix} u_k(\tau_{k+1}) \\ v_k(\tau_{k+1}) \end{bmatrix} = \begin{bmatrix} u_k(\tau_k) \\ v_k(\tau_k) \end{bmatrix} - \phi|_K(\tau_k)$
2204
propagate $y_K(\tau_k)$ to $y_K(\tau_k + \Delta\tau_k)$
2205
convergence ?
Y
return
2206
N
$\tau_k < T_K$?
Y
2207
N
$\tau_{k+1} = \tau_k + \Delta\tau_k$
$K = K+1$
2208
$P_{K+1}(T_k) =$
$H(T_k) Q G(T_k)$
$P_{K+1}(0)$ = computed value
2209
$y_{K+1}(0) = y_K(\tau_k)$
compute T_{K+1}
$\tau = 0$
$k = 0$
$K = K+1$
2210

Figure 22

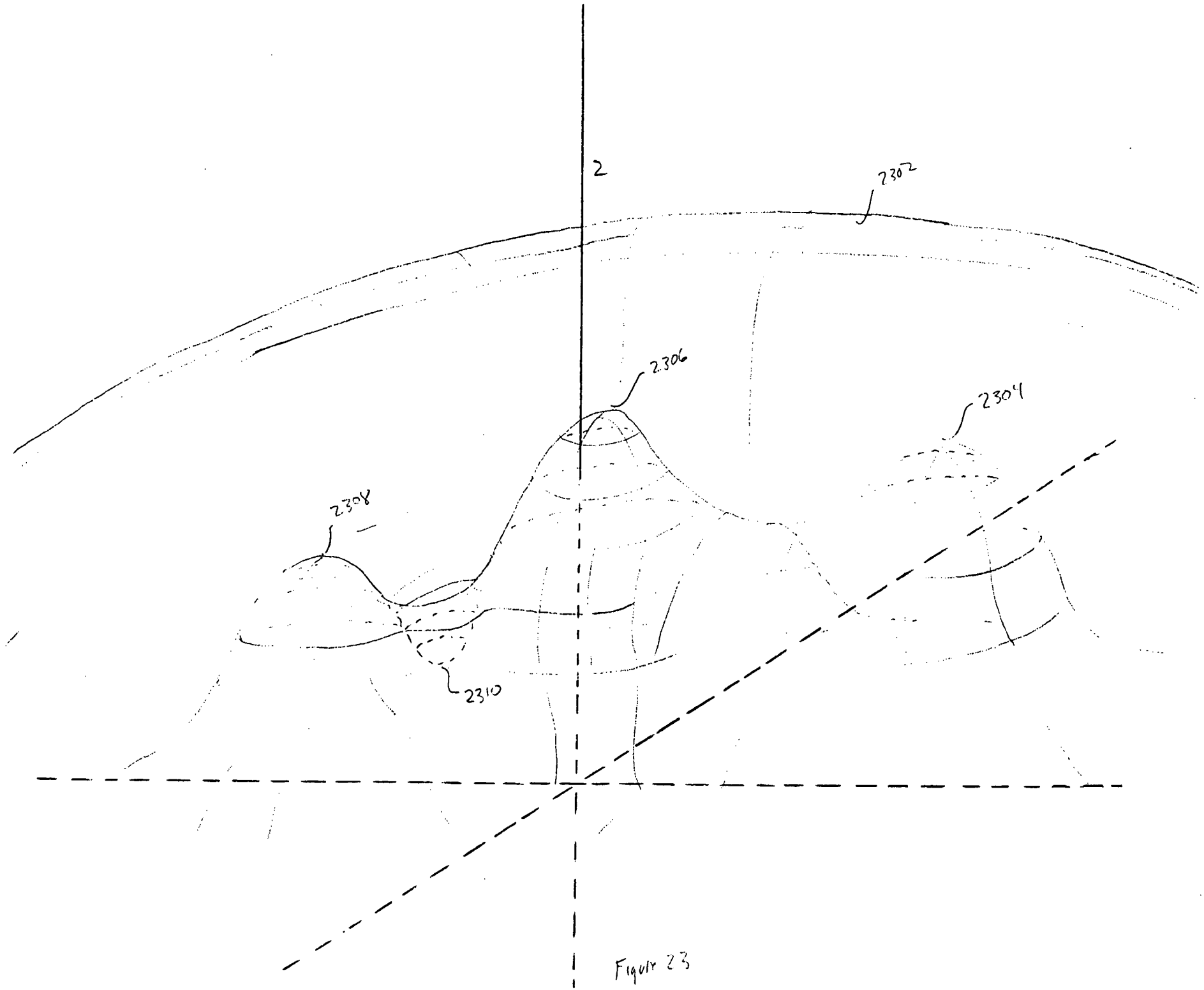


Figure 23

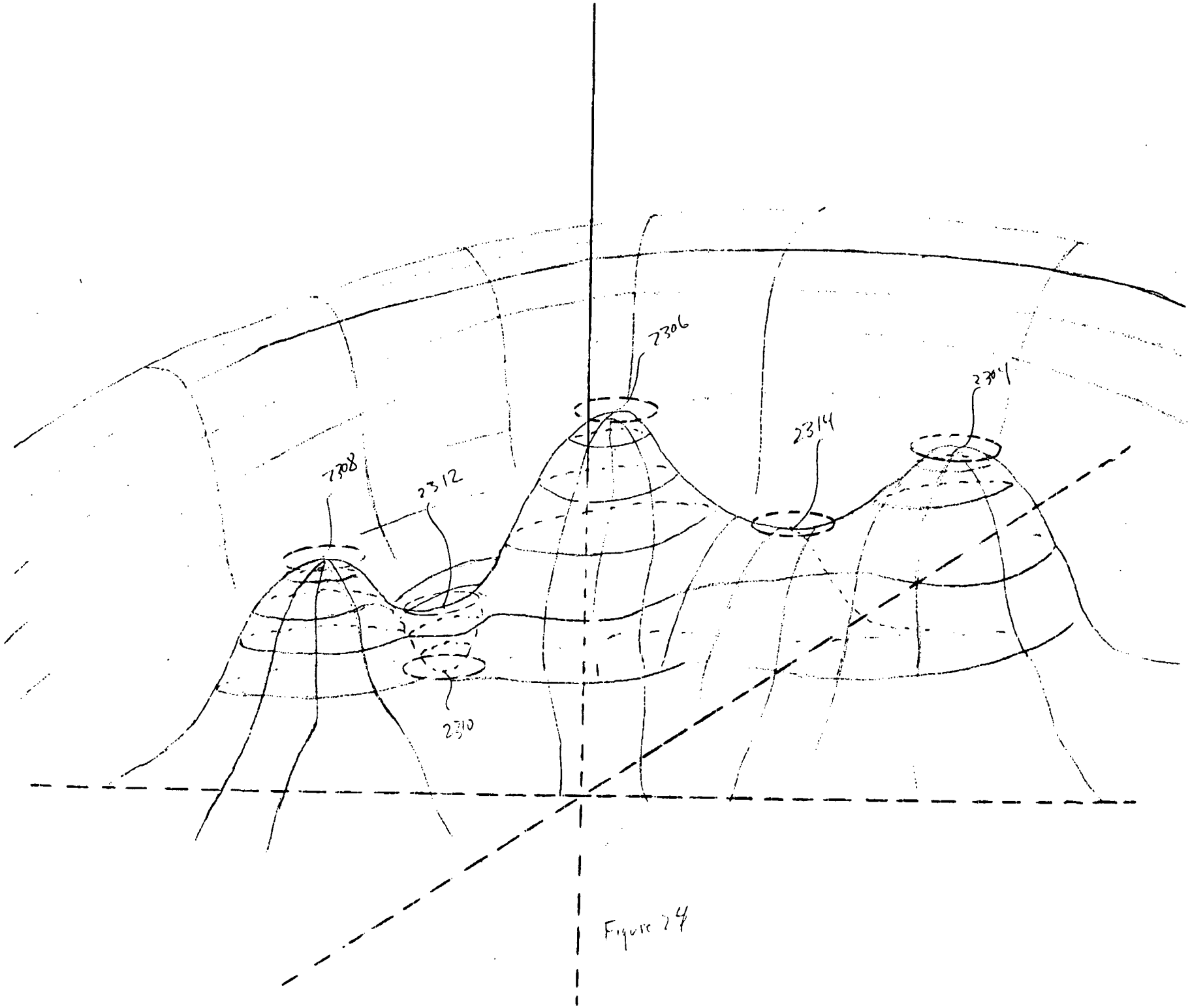


Figure 24

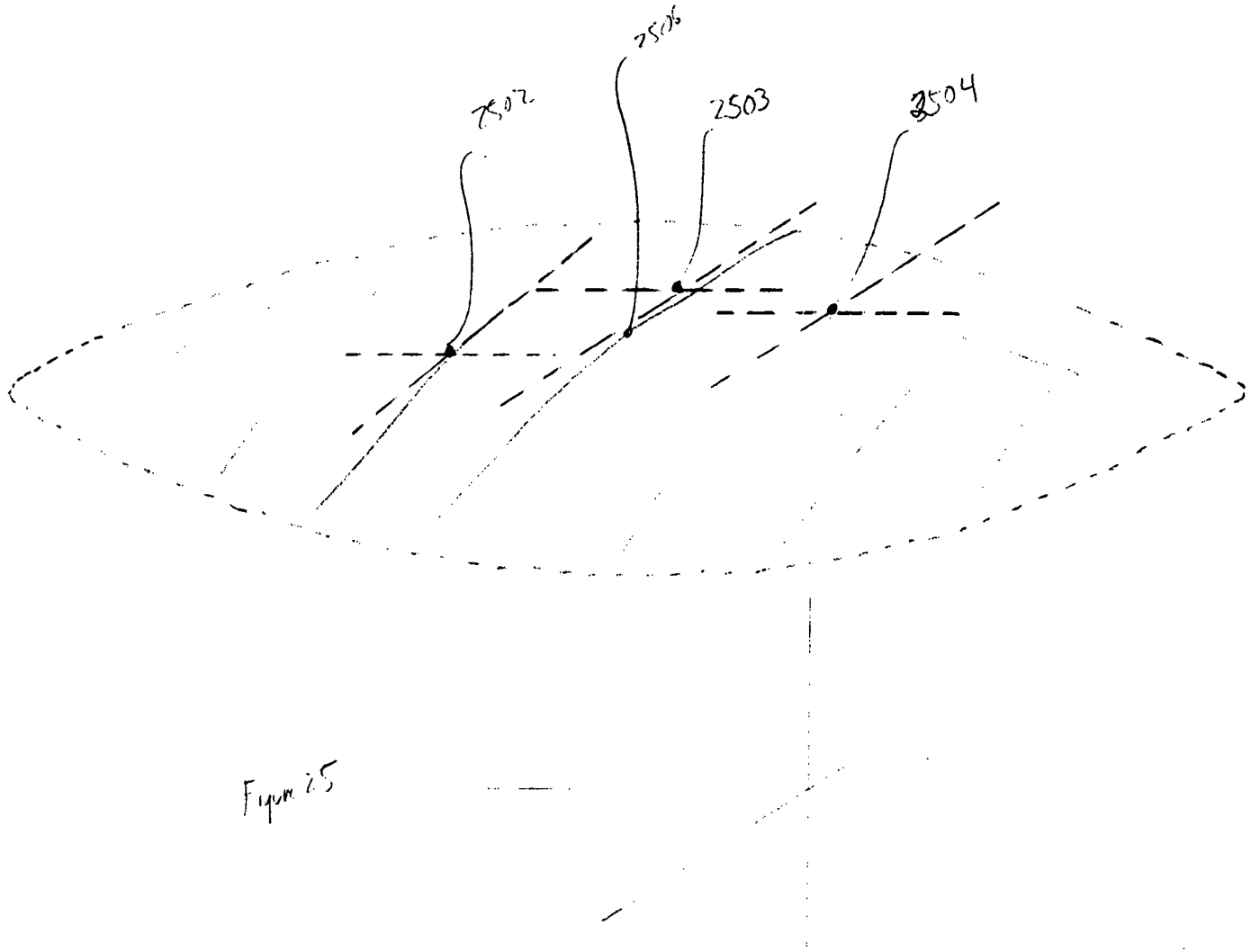


Figure 25

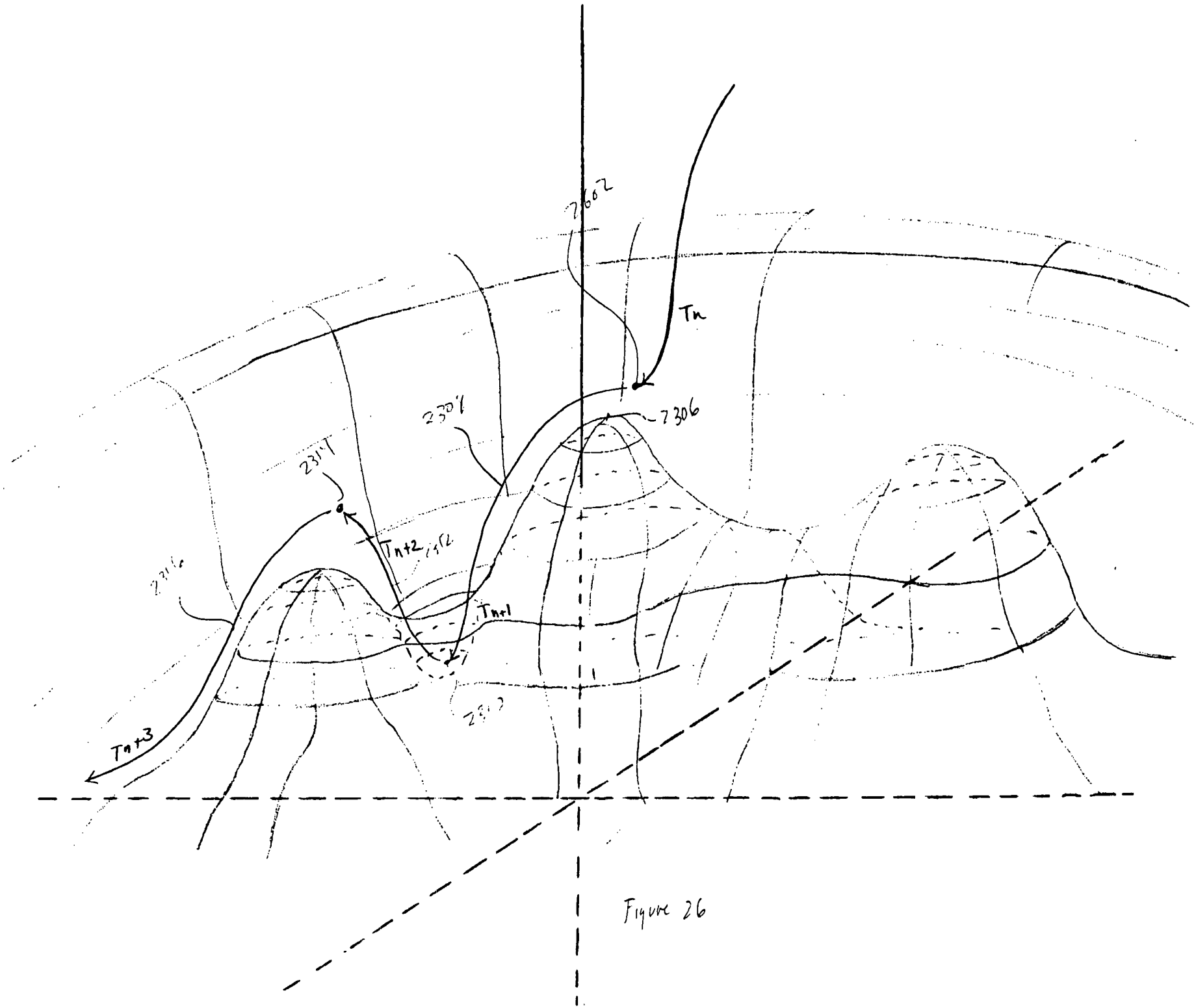


Figure 26

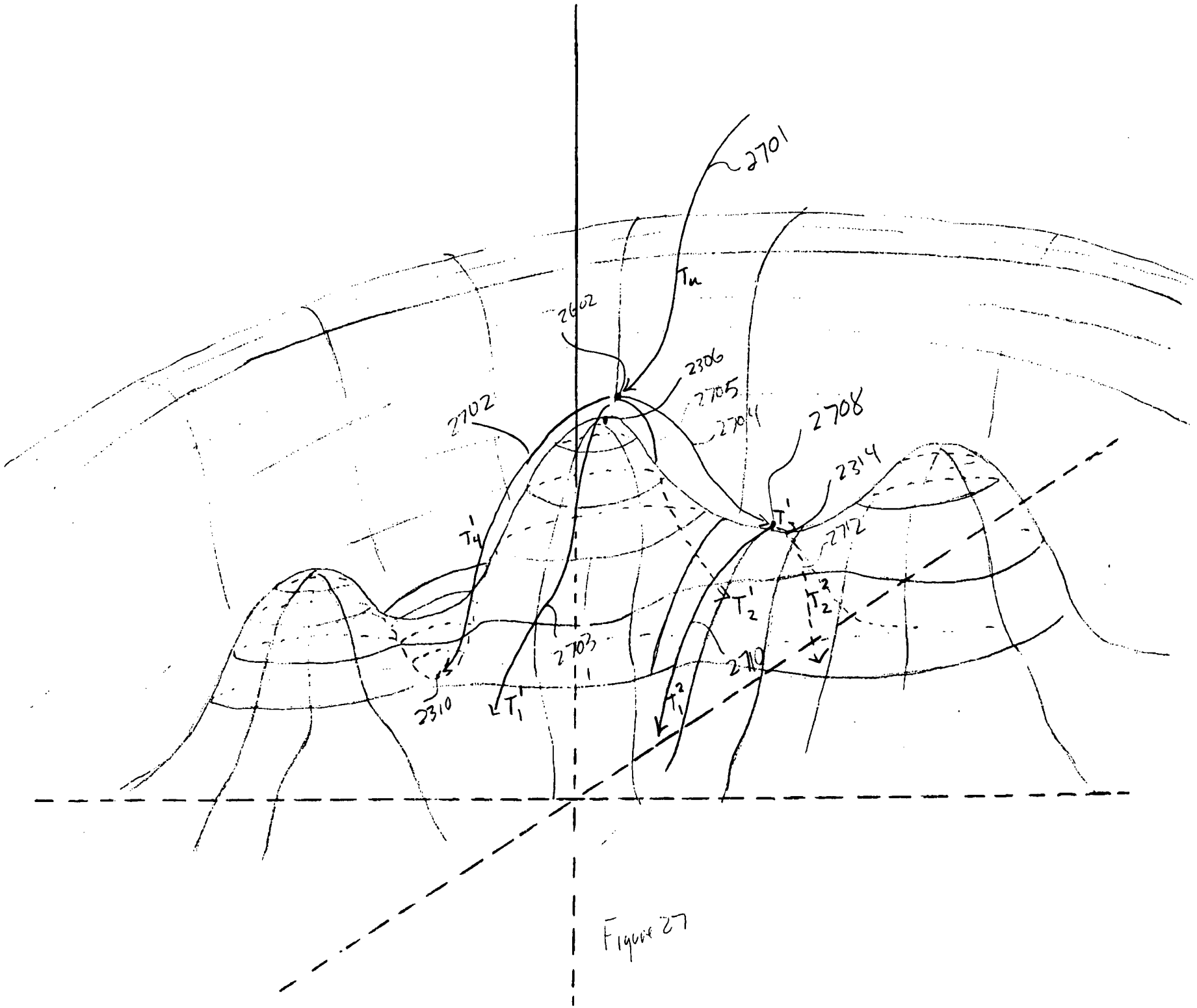

2701
T_m
2602
2306
2705
2704
2708
2702
2314
T_4'
T_3'
2712
T_2'
T_2^2
2703
2710
2310
T_1'
T_1^2

Figure 27

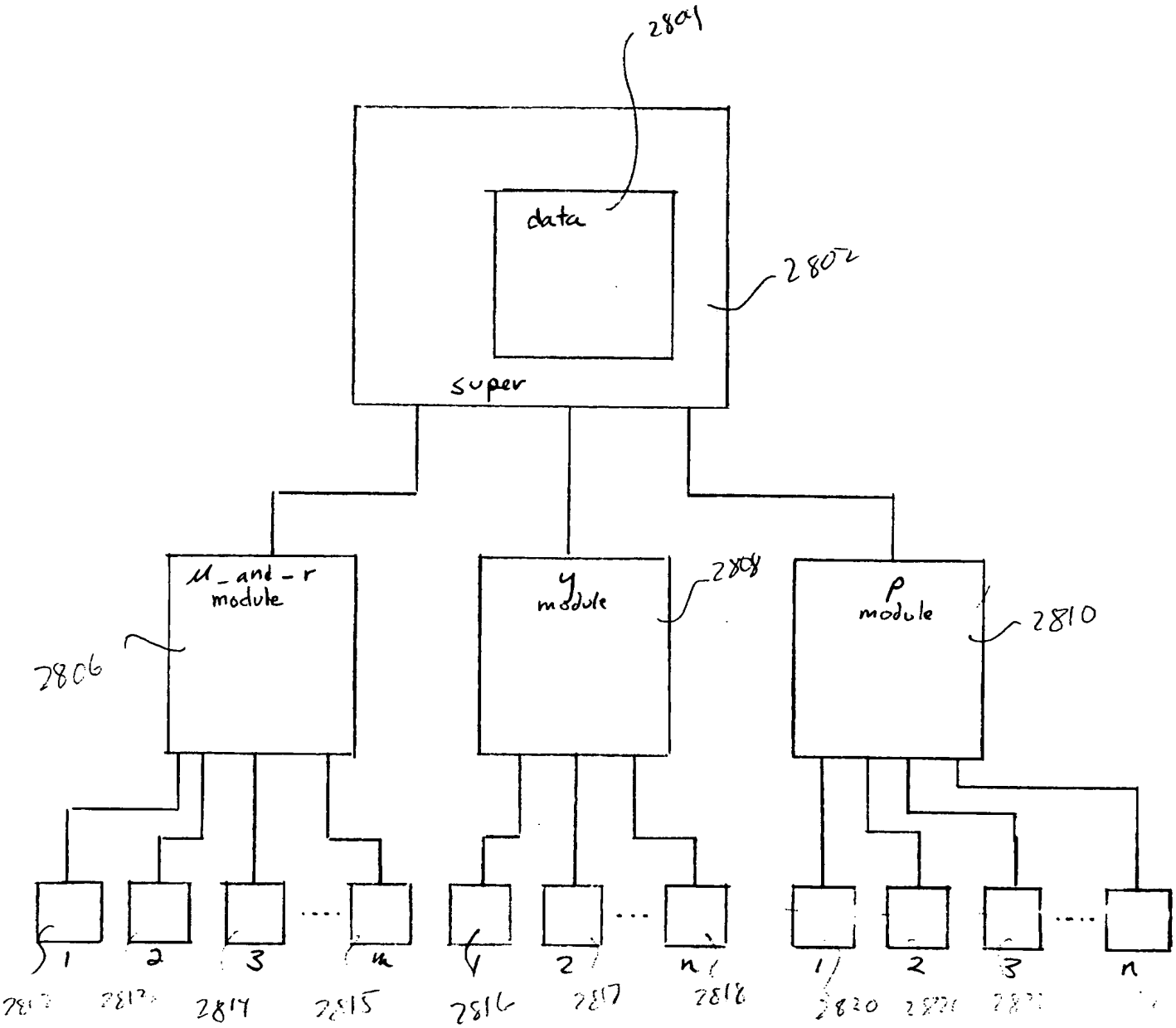

2804
data
2802
super
m_and_r module
2806
y module
2808
p module
2810
1
2
3
m
1
2
n
1
2
3
n
2813
2814
2815
2816
2817
2818
2820

Figure 28

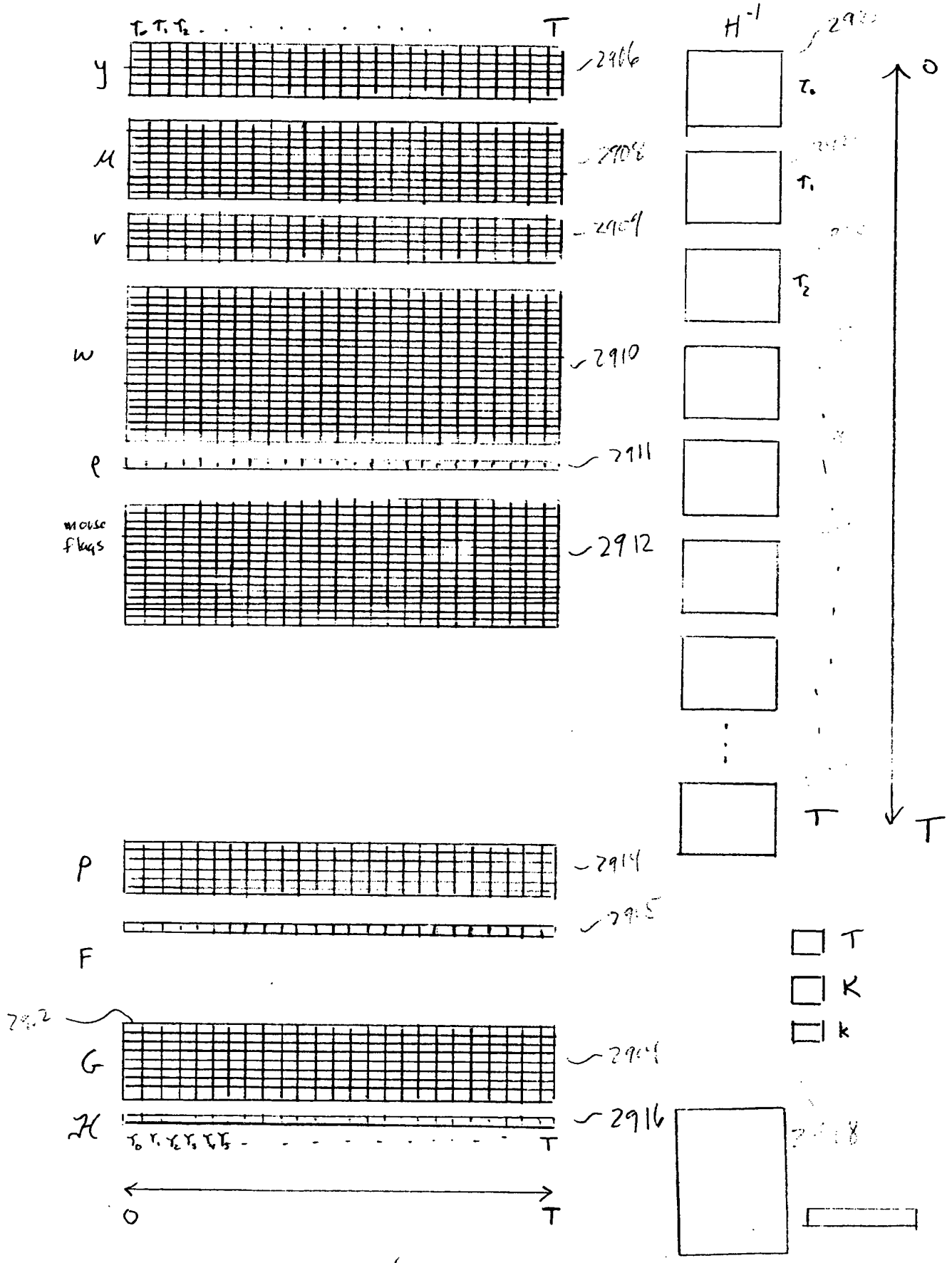
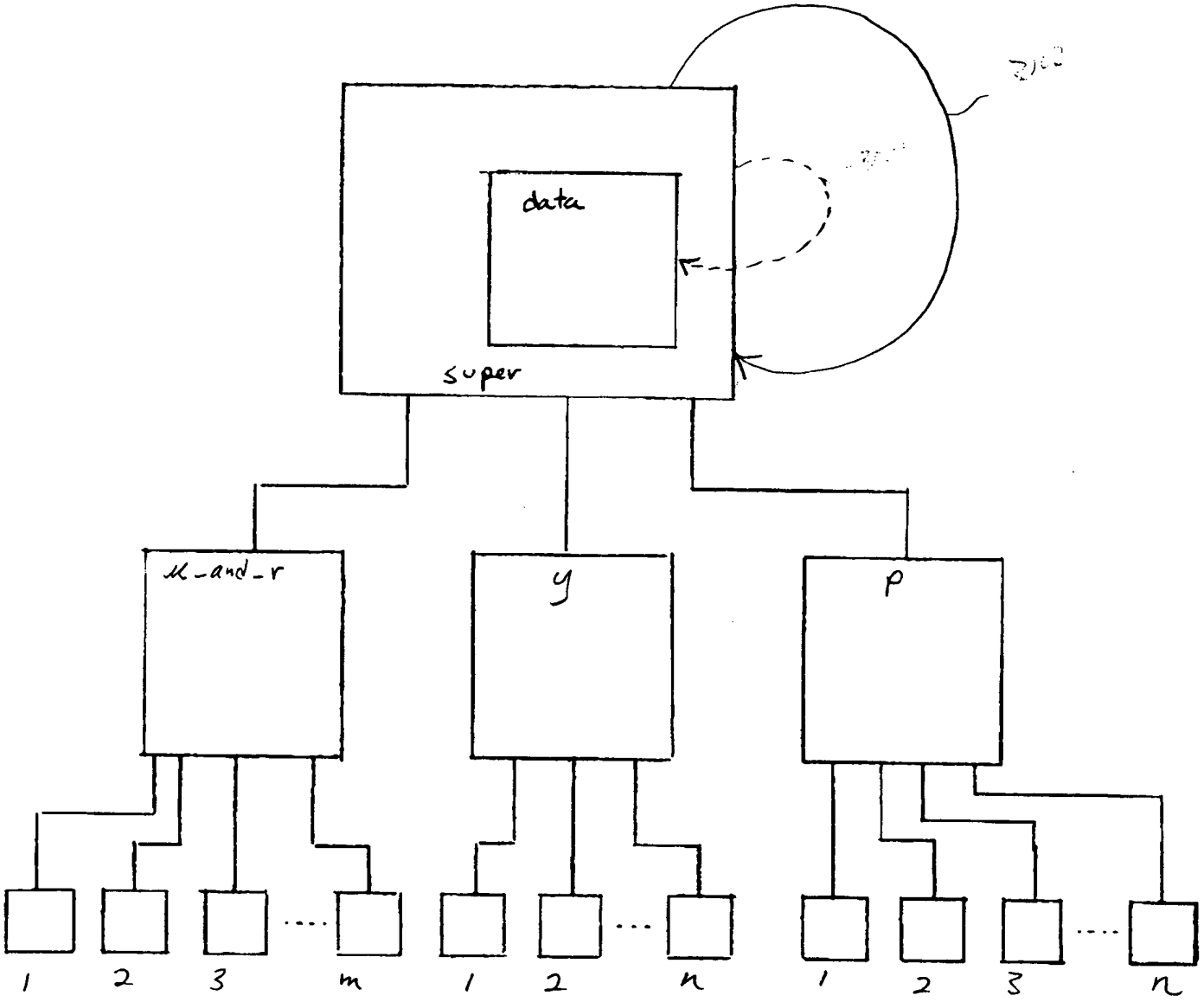
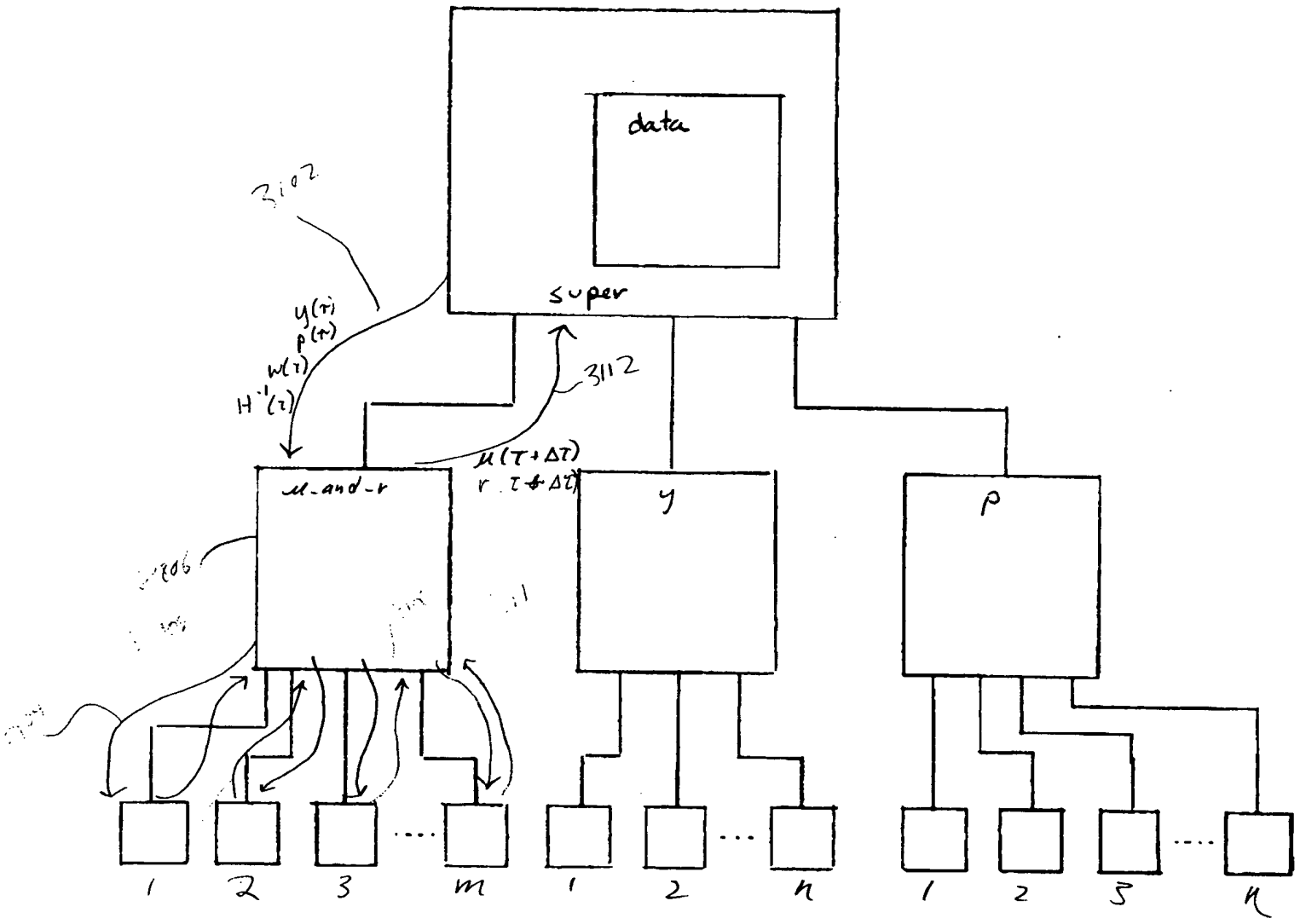
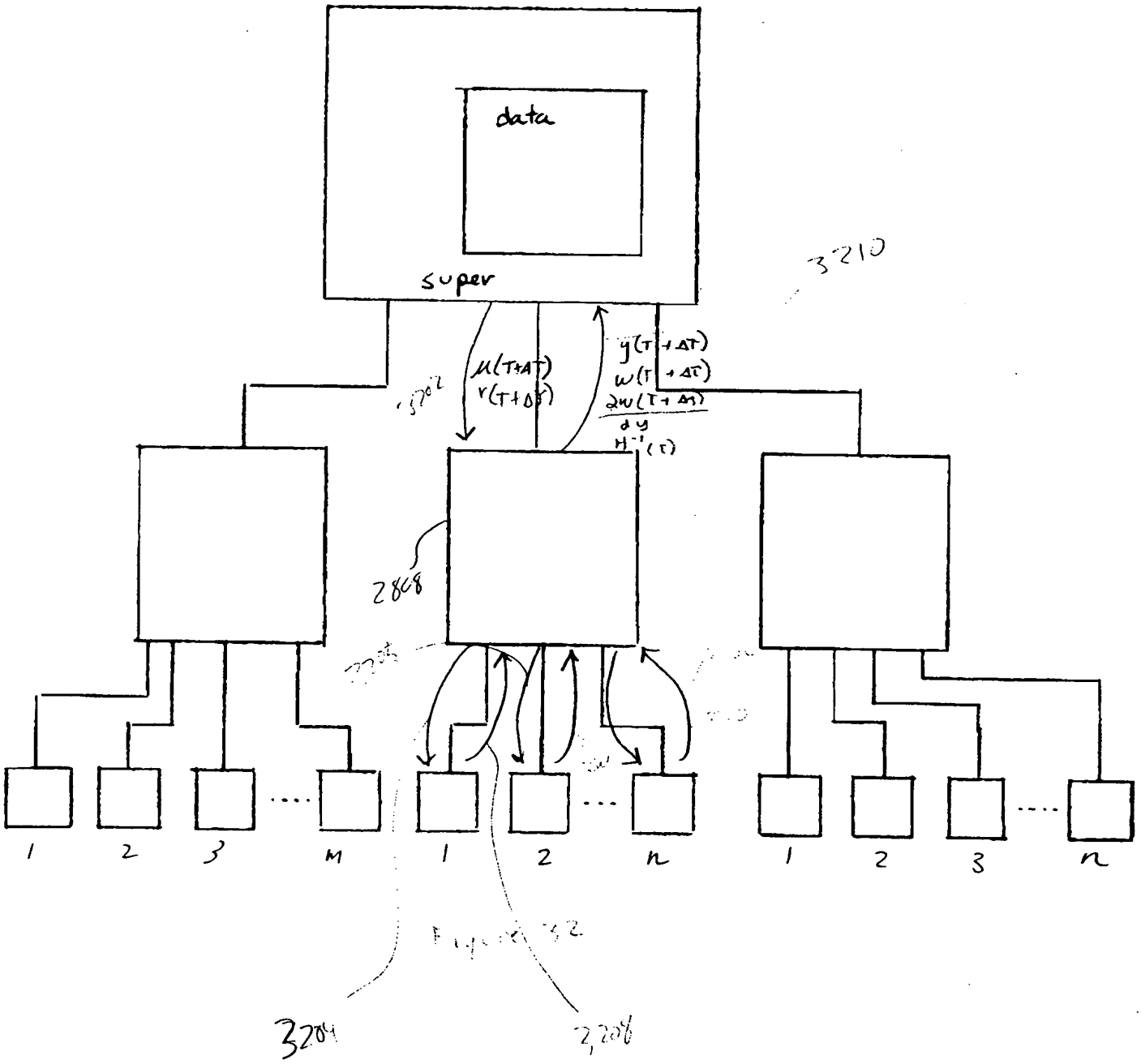
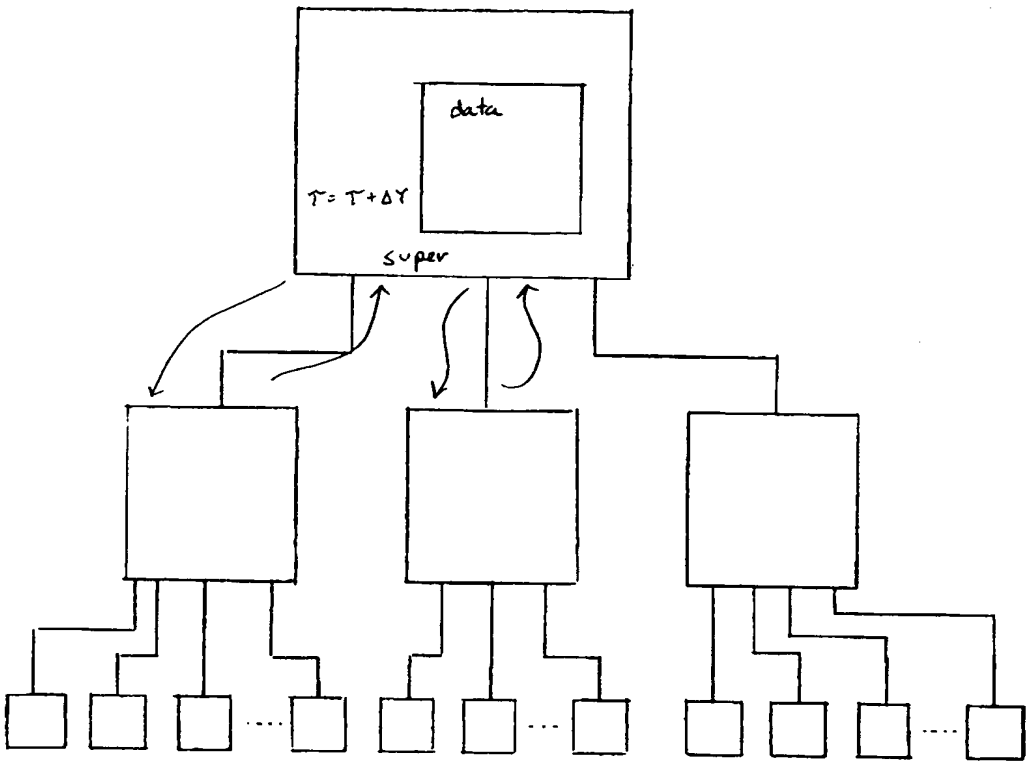

$\tau_0 \tau_1 \tau_2 \ldots \ldots \ldots T$
y
2906
M
2908
r
2909
w
2910
p
2911
mouse flags
2912
H^{-1}
2913
τ_0
τ_1
τ_2
T
0
T
P
2914
2915
F
T
K
k
2902
G
2904
H
2916
$\tau_0 \tau_1 \tau_2 \tau_3 \tau_4 \tau_5 \ldots \ldots \ldots T$
0
T

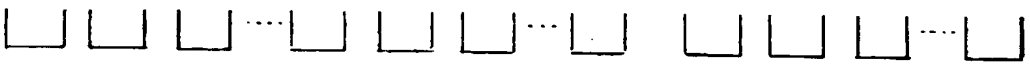
Figure 29


data
super
x_and_r
y
p
1
2
3
m
1
2
n
1
2
3
n


data
super
y(τ)
p(τ)
w(τ)
H⁻¹(τ)
μ(τ+Δτ)
μ_and_r
y
p
1
2
3
m
1
2
n
1
2
3
n


data
super
3210
$\mu(T+\Delta T)$
$\nu(T+\Delta T)$
$g(T+\Delta T)$
$w(T+\Delta T)$
$\frac{\partial w(T+\Delta T)}{\partial y}$
$H^{-1}(T)$
2808
1
2
3
M
1
2
n
1
2
3
n
3204
2,206


data
T = T + ΔT
super



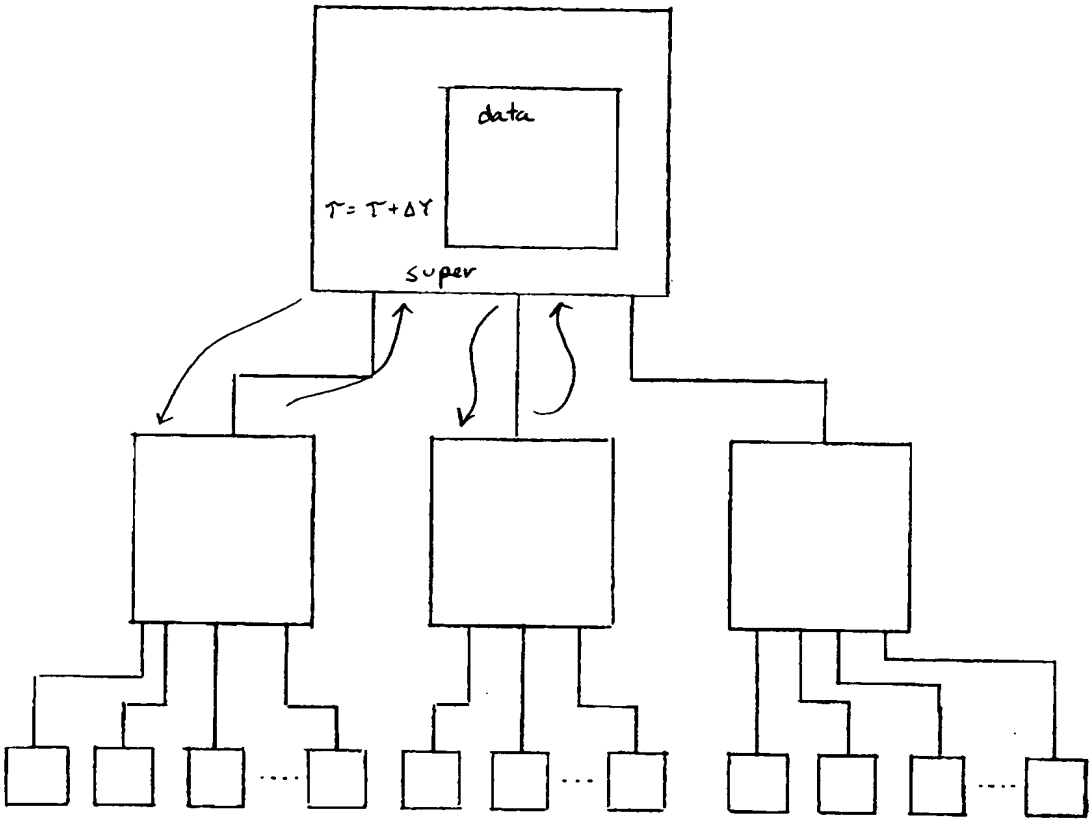
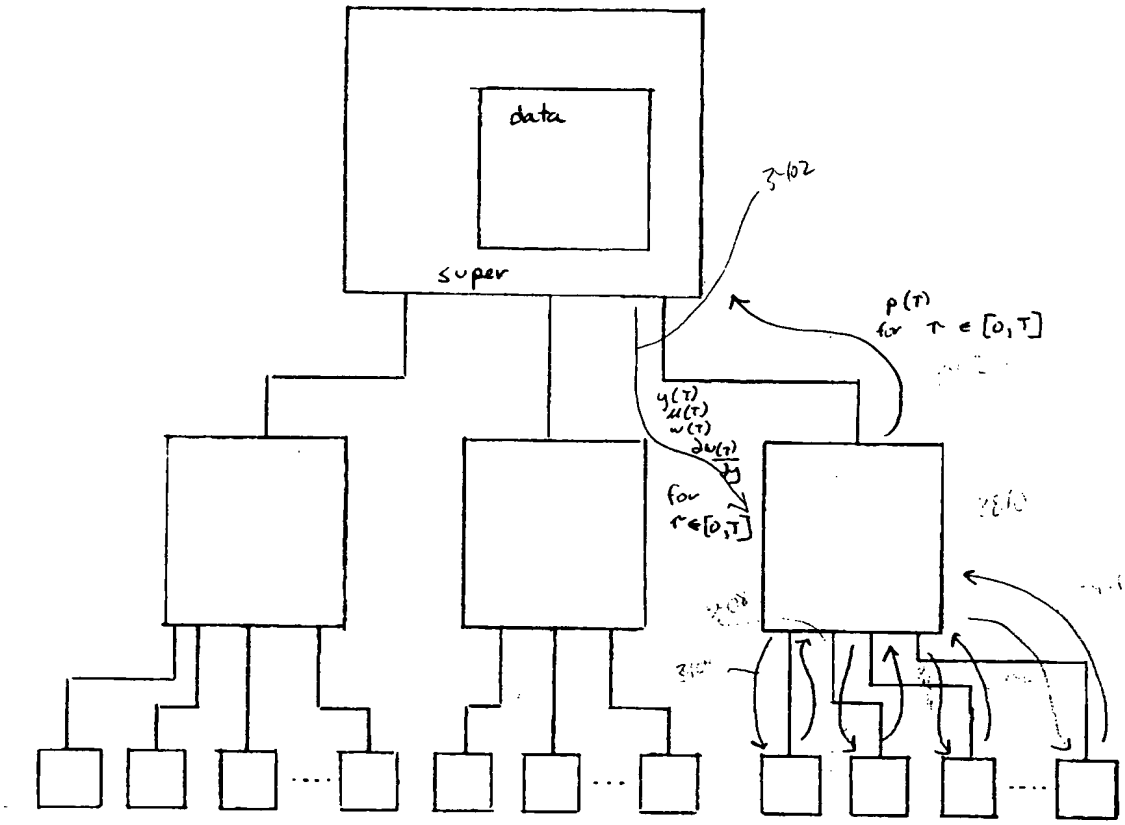
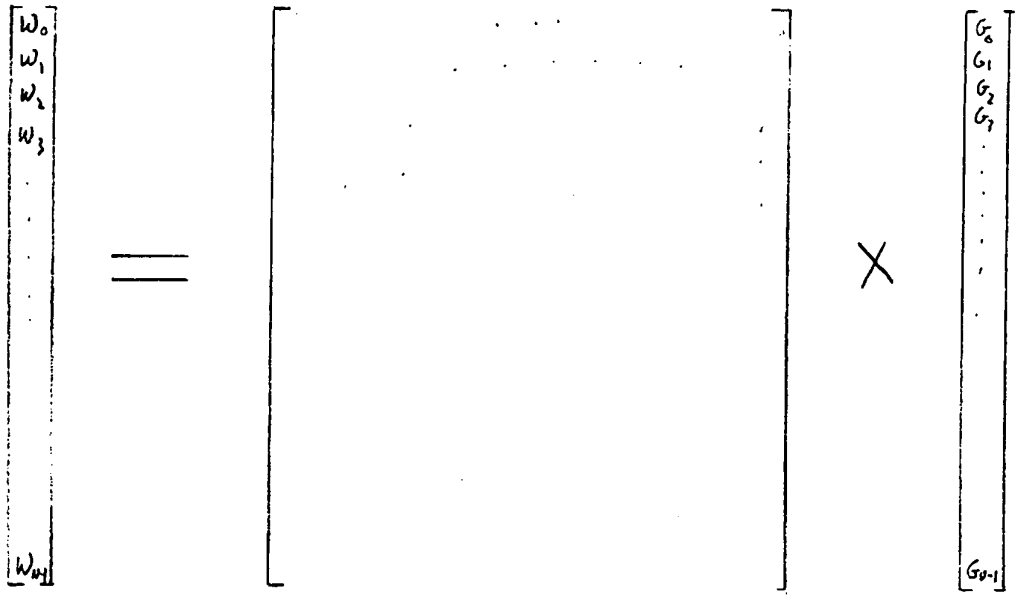


Figure 53


data
super
p(τ)
for τ ∈ [0,T]
y(τ)
u(τ)
w(τ)
for
τ∈[0,T]



w H^{-1} G

Figure 35

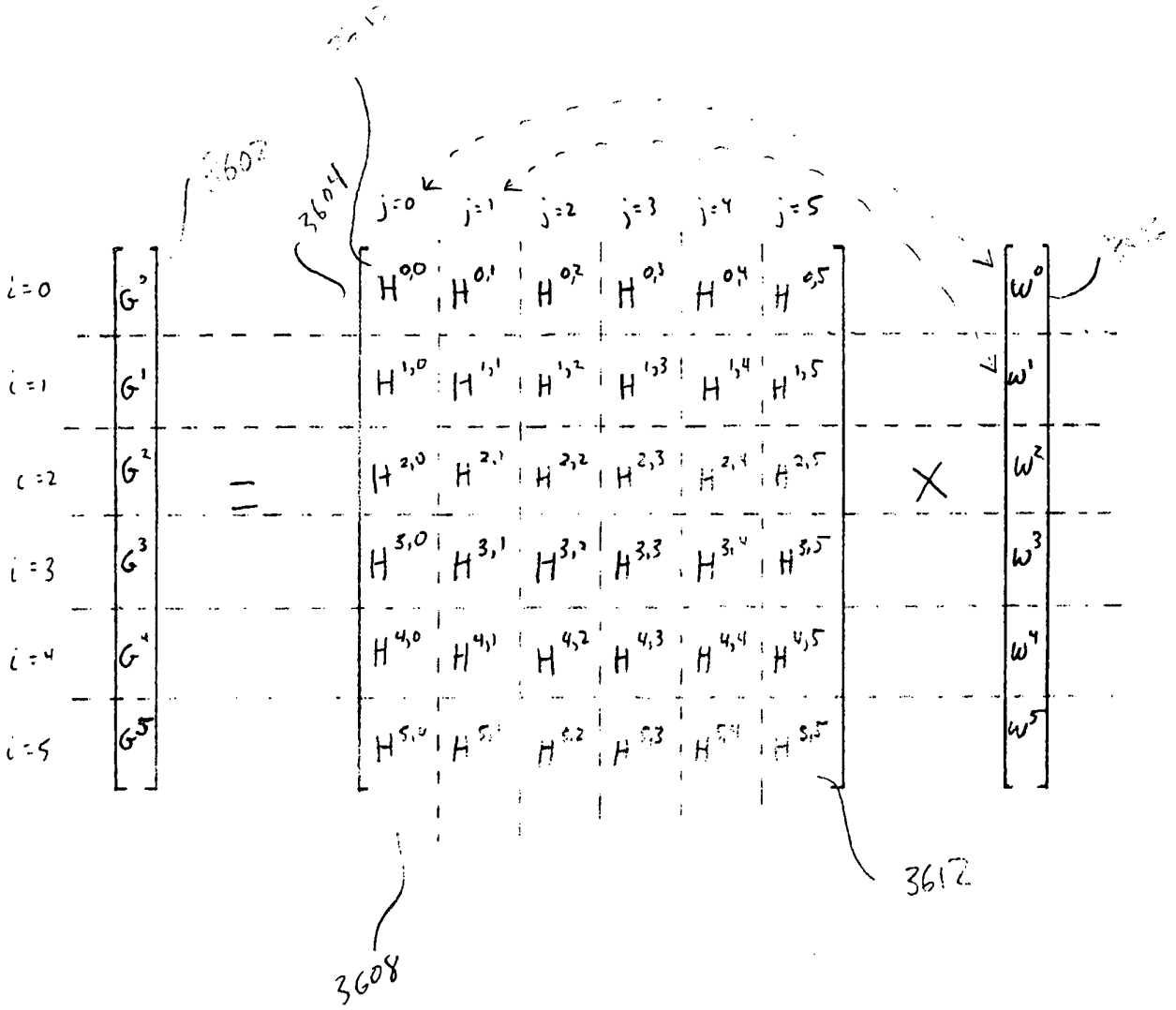


Figure 36

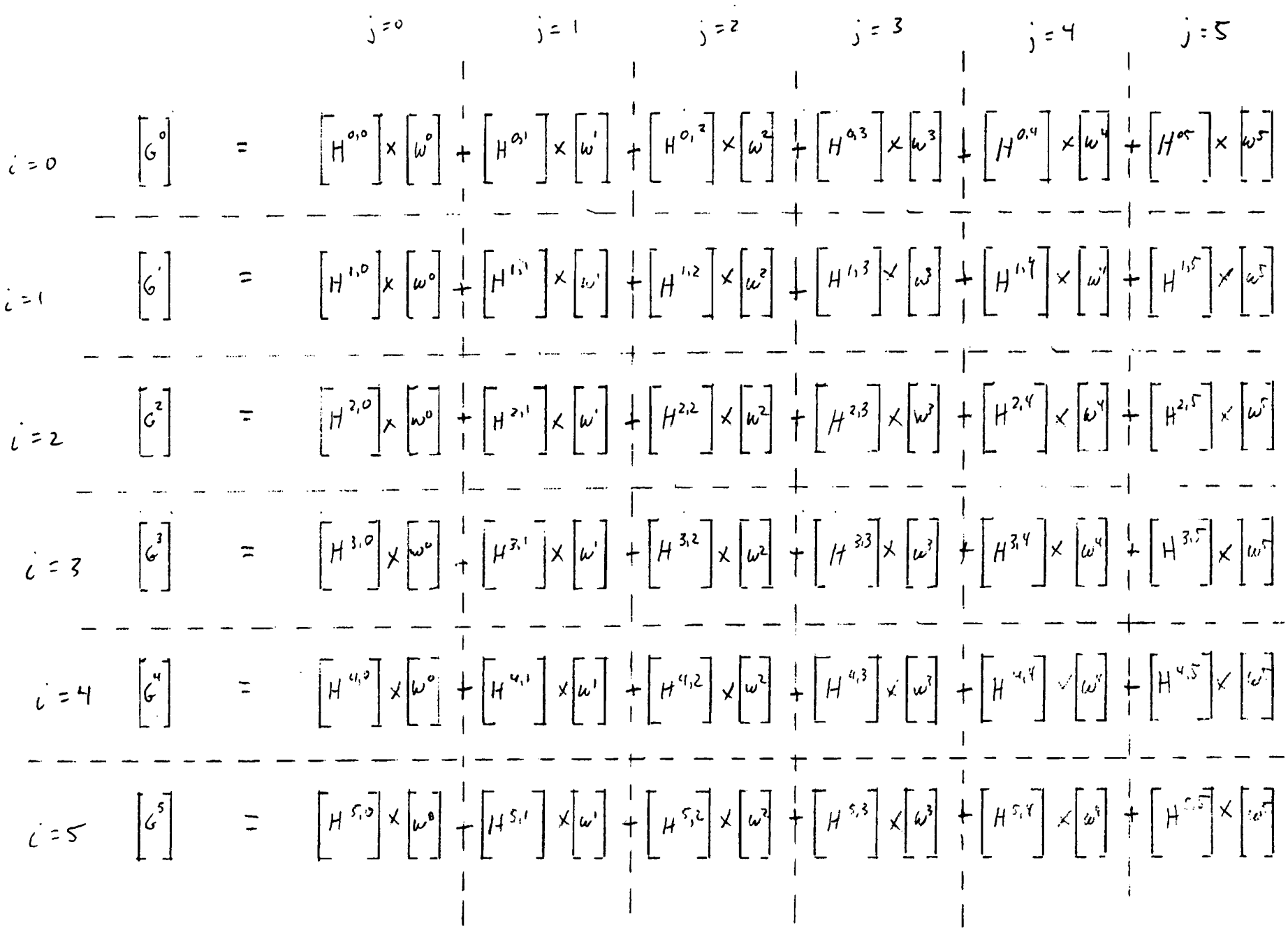

j = 0
j = 1
j = 2
j = 3
j = 4
j = 5
i = 0 [G^0] = [H^0,0] x [w^0] + [H^0,1] x [w^1] + [H^0,2] x [w^2] + [H^0,3] x [w^3] + [H^0,4] x [w^4] + [H^0,5] x [w^5]
i = 1 [G^1] = [H^1,0] x [w^0] + [H^1,1] x [w^1] + [H^1,2] x [w^2] + [H^1,3] x [w^3] + [H^1,4] x [w^4] + [H^1,5] x [w^5]
i = 2 [G^2] = [H^2,0] x [w^0] + [H^2,1] x [w^1] + [H^2,2] x [w^2] + [H^2,3] x [w^3] + [H^2,4] x [w^4] + [H^2,5] x [w^5]
i = 3 [G^3] = [H^3,0] x [w^0] + [H^3,1] x [w^1] + [H^3,2] x [w^2] + [H^3,3] x [w^3] + [H^3,4] x [w^4] + [H^3,5] x [w^5]
i = 4 [G^4] = [H^4,0] x [w^0] + [H^4,1] x [w^1] + [H^4,2] x [w^2] + [H^4,3] x [w^3] + [H^4,4] x [w^4] + [H^4,5] x [w^5]
i = 5 [G^5] = [H^5,0] x [w^0] + [H^5,1] x [w^1] + [H^5,2] x [w^2] + [H^5,3] x [w^3] + [H^5,4] x [w^4] + [H^5,5] x [w^5]

Figure 37

$$\left[G^i\right] = \left[H^{i,0}\right]\times\left[w^0\right] + \left[H^{i,1}\right]\times\left[w^1\right] + \left[H^{i,2}\right]\times\left[w^2\right] + \left[H^{i,3}\right]\times\left[w^3\right] + \left[H^{i,4}\right]\times\left[w^4\right] + \left[H^{i,5}\right]\times\left[w^5\right]$$

when $i = 1$, for example

$$\left[G^1\right] = \left[H^{1,1}\right]\times\left[w^1\right] + \left[\left[H^{1,0}\right]\times\left[w^0\right] + \left[H^{1,2}\right]\times\left[w^2\right] + \left[H^{1,3}\right]\times\left[w^3\right] + \left[H^{1,4}\right]\times\left[w^4\right] + \left[H^{1,5}\right]\times\left[w^5\right]\right]$$

$$\left[G^1\right] - \left[\left[H^{1,0}\right]\times\left[w^0\right] + \left[H^{1,2}\right]\times\left[w^2\right] + \left[H^{1,3}\right]\times\left[w^3\right] + \left[H^{1,4}\right]\times\left[w^4\right] + \left[H^{1,5}\right]\times\left[w^5\right]\right] = \left[H^{1,1}\right]\left[w^1\right]$$

$$\left[H^{1,1}\right]^{-1}\left[\left[G^1\right] - \left[\left[H^{1,0}\right]\times\left[w^0\right] + \left[H^{1,2}\right]\times\left[w^2\right] + \left[H^{1,3}\right]\times\left[w^3\right] + \left[H^{1,4}\right]\times\left[w^4\right] + \left[H^{1,5}\right]\times\left[w^5\right]\right]\right] = \left[w^1\right]$$

Figure 38

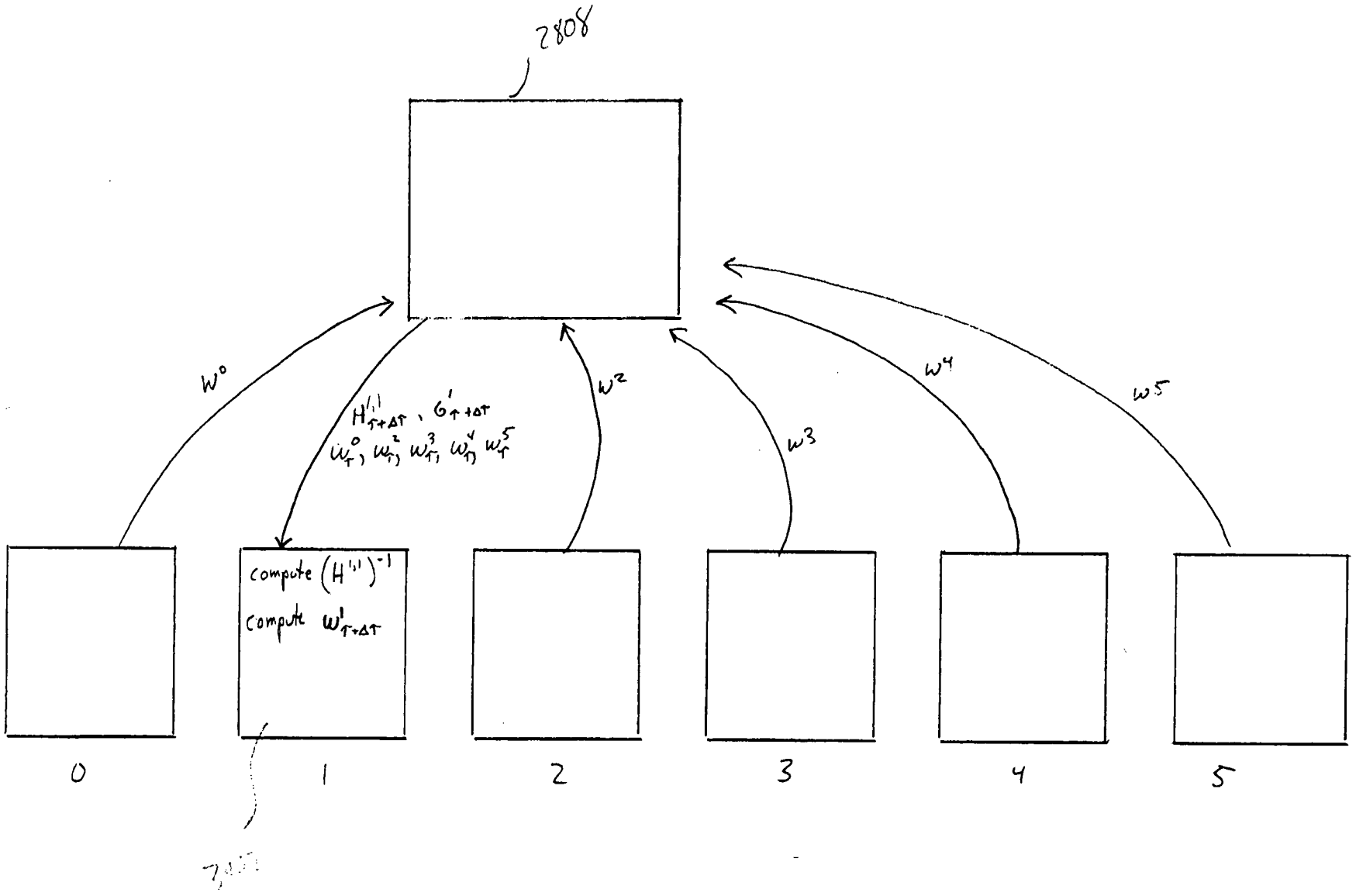

2808
w^0
$H^{1,1}_{\tau+\Delta\tau}$, $G'_{\tau+\Delta\tau}$
w^0_τ, w^2_τ, w^3_τ, w^4_τ, w^5_τ
w^2
w^3
w^4
w^5
compute $(H^{1,1})^{-1}$
compute $w'_{\tau+\Delta\tau}$
0
1
2
3
4
5

Figure 29

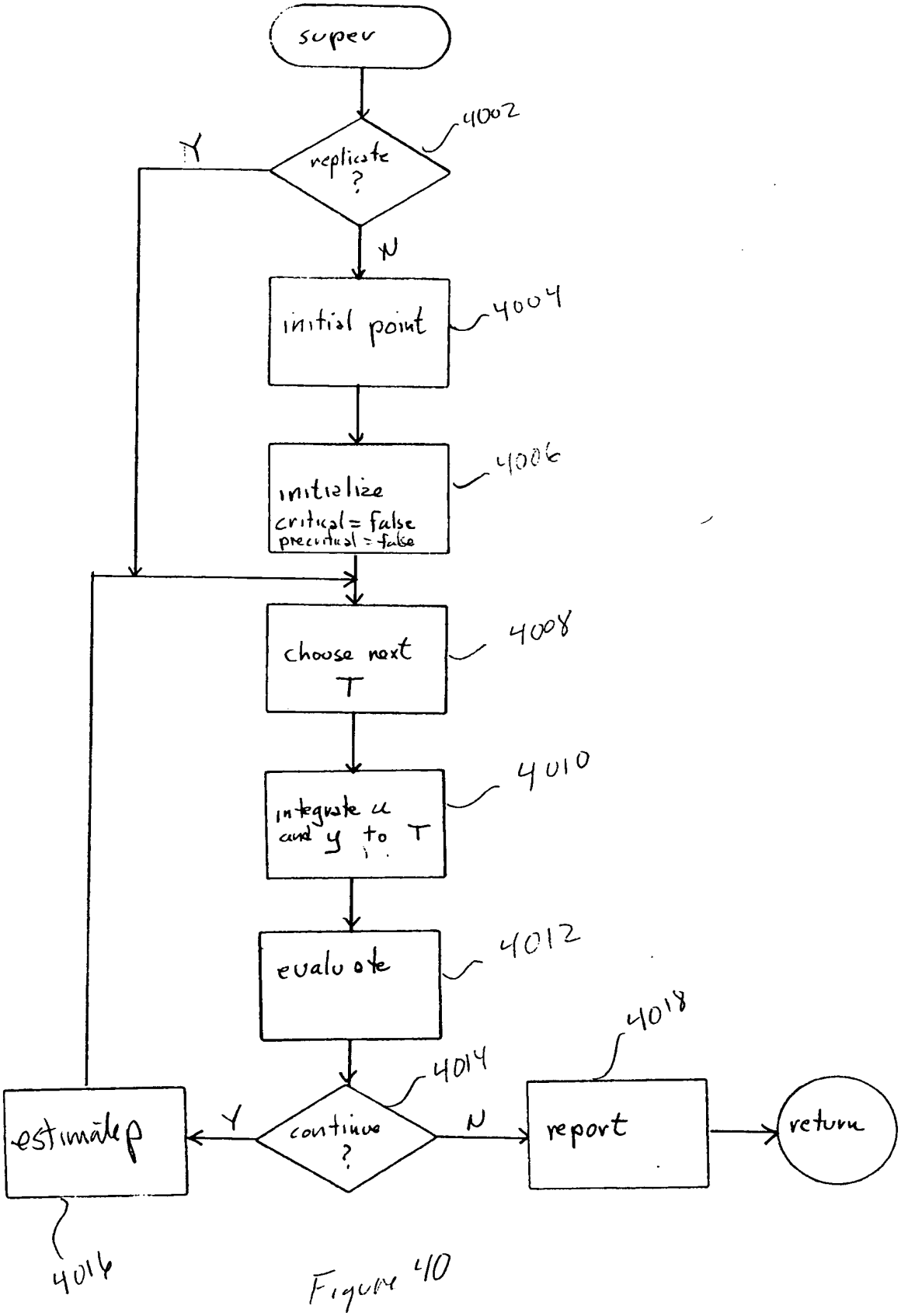

super
4002
replicate ?
Y
N
initial point
4004
initialize
critical = false
precritical = false
4006
choose next T
4008
integrate u and y to T
4010
evaluate
4012
4014
continue ?
Y
N
estimate p
4016
4018
report
return

Figure 40

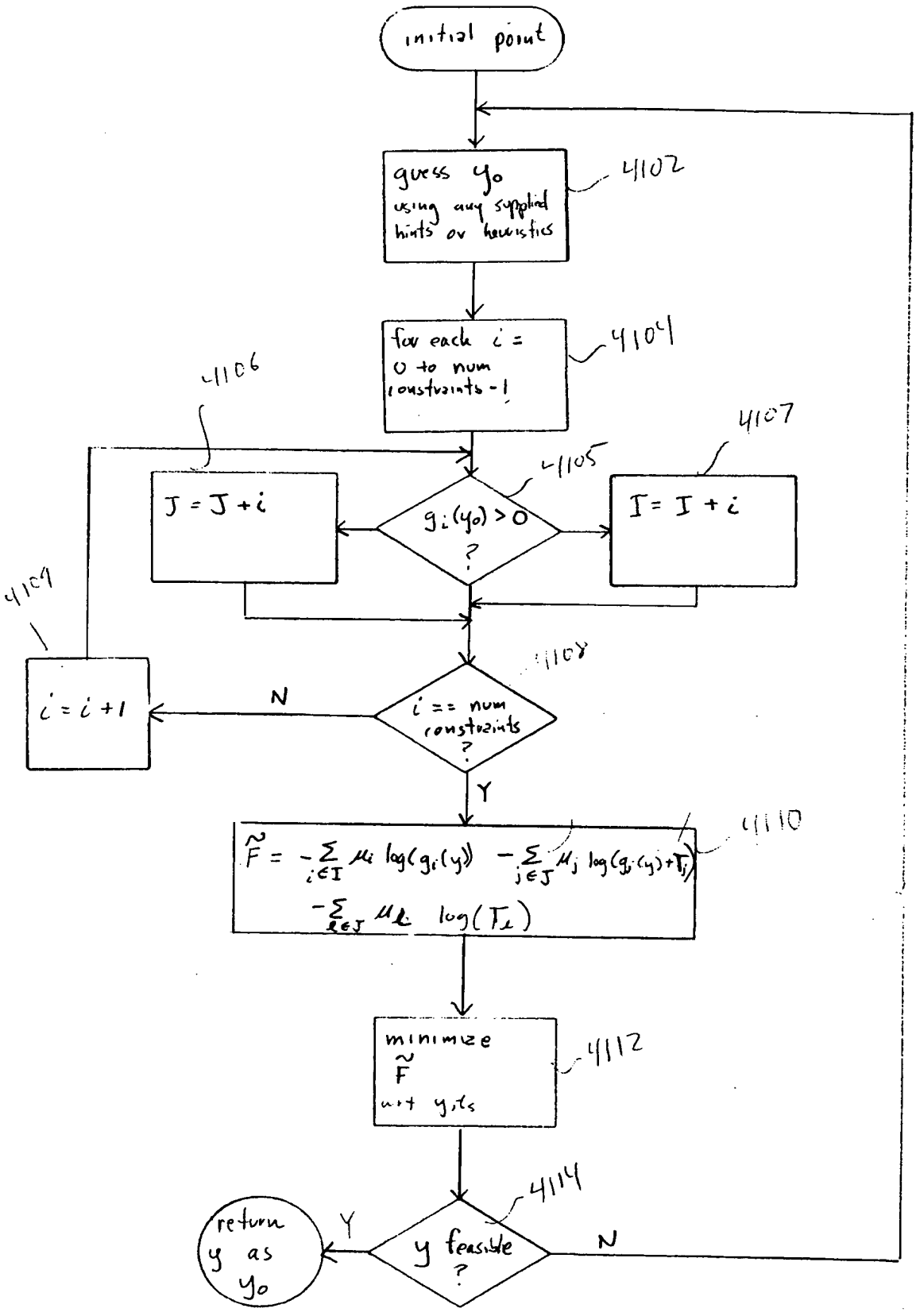

initial point
guess y_0 using any supplied hints or heuristics
4102
for each i = 0 to num constraints - 1
4104
4106
4107
4105
$J = J + i$
$g_i(y_0) > 0$?
$I = I + i$
4109
$i = i + 1$
N
4108
i == num constraints ?
Y
4110
$\tilde{F} = -\sum_{i \in I} \mu_i \log(g_i(y)) - \sum_{j \in J} \mu_j \log(g_j(y) + T_j) - \sum_{k \in J} \mu_k \log(T_k)$
minimize $\tilde{F}$ wrt y, t_s
4112
4114
return y as y_0
Y
y feasible ?
N

Figure 41

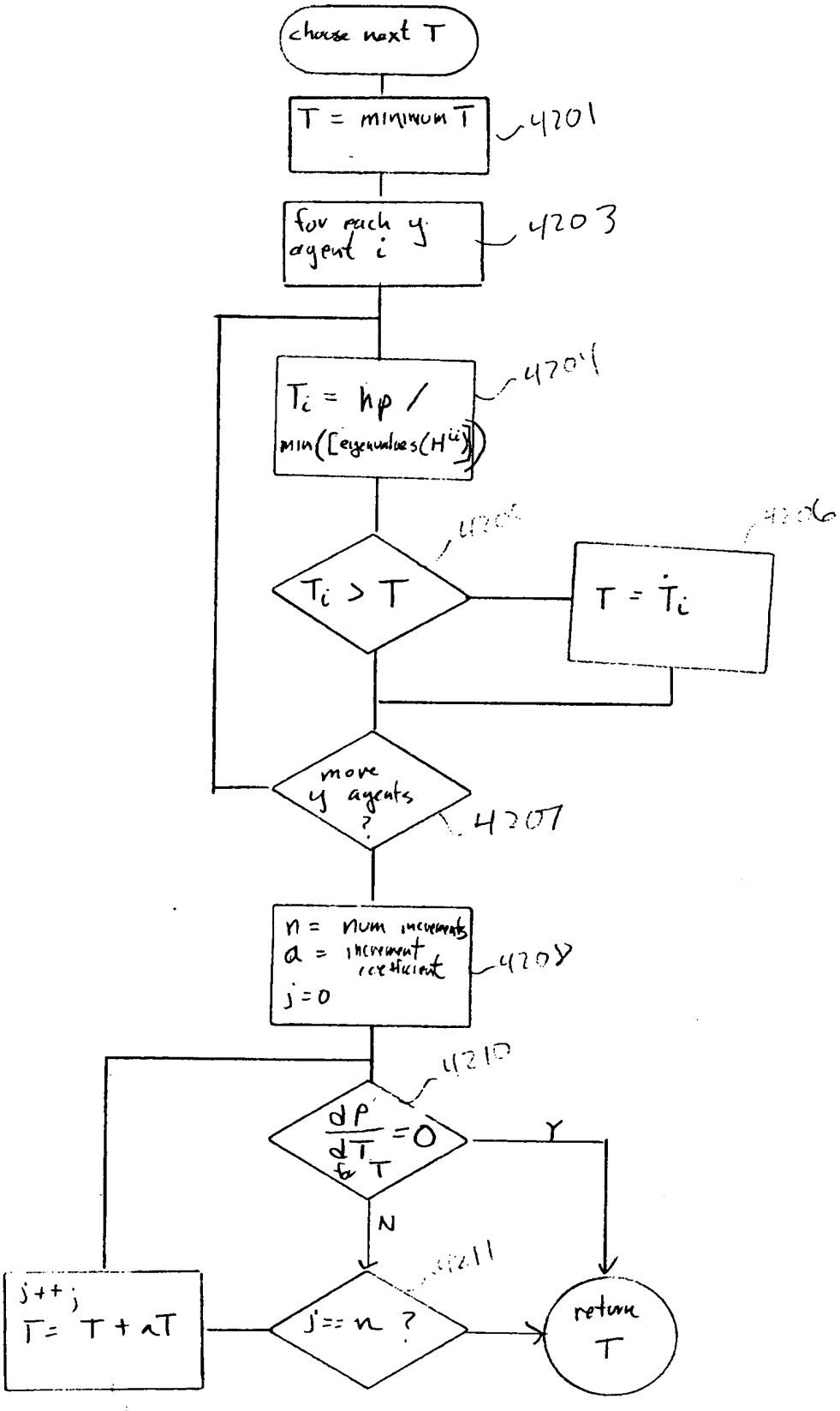

choose next T
T = minimum T
4201
for each y agent i
4203
T_i = hp / min([eigenvalues(H^{ii})])
4204
$T_i > T$
4206
T = T_i
move y agents ?
4207
n = num increments
a = increment coefficient
j = 0
4209
4210
$\frac{dP}{dT}_{\text{for } T} = 0$
Y
N
4211
j++;
T = T + aT
j == n ?
return T

Figure 12

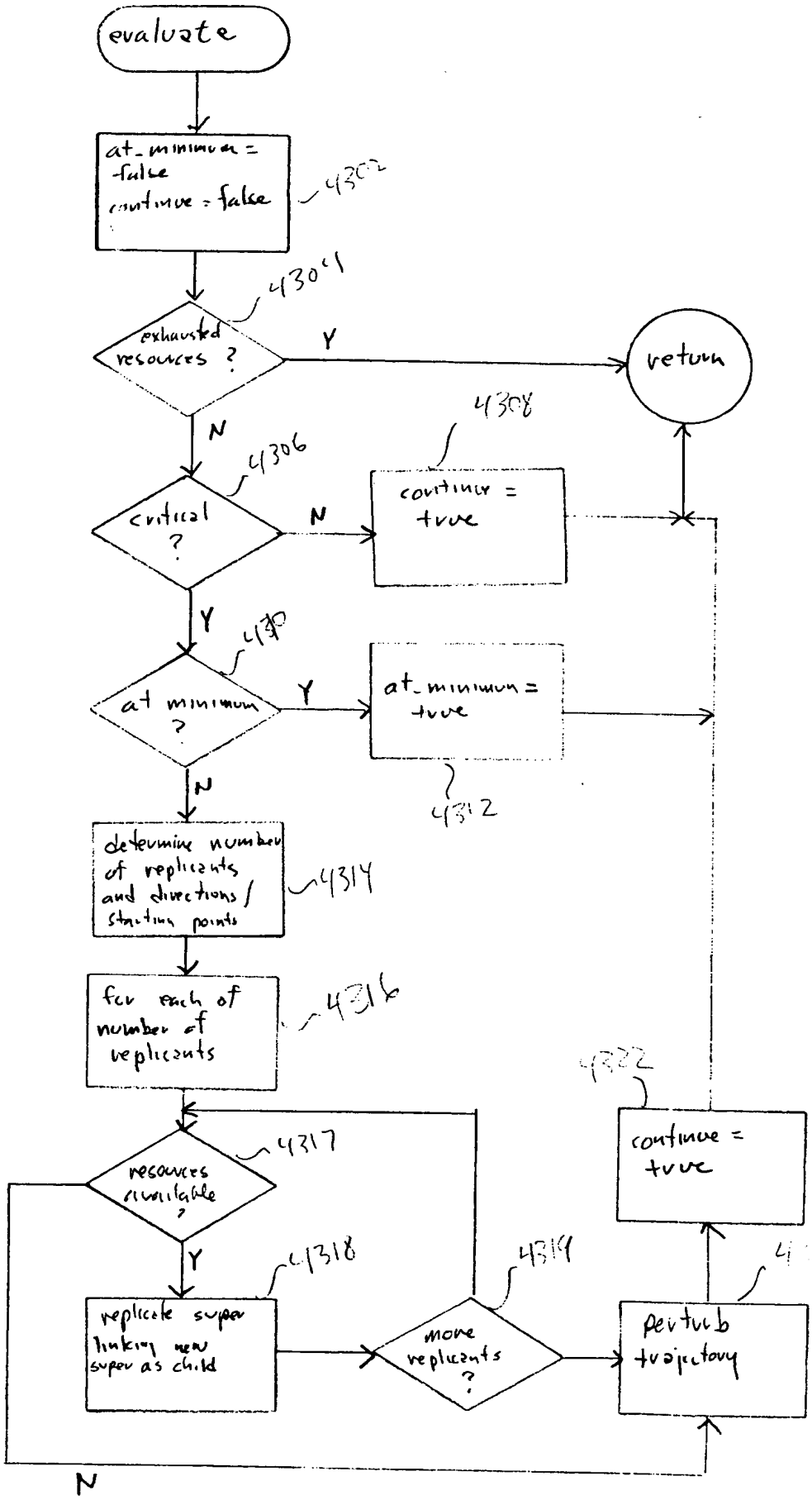

evaluate
at_minimum = false
continue = false
4302
4301
exhausted resources ?
Y
return
N
4308
4306
critical ?
N
continue = true
Y
4310
at minimum ?
Y
at_minimum = true
N
4312
determine number of replicants and directions / starting points
4314
for each of number of replicants
4316
4322
continue = true
4317
resources available ?
Y
4318
4319
replicate super linking new super as child
more replicants ?
perturb trajectory
N

Figure 43

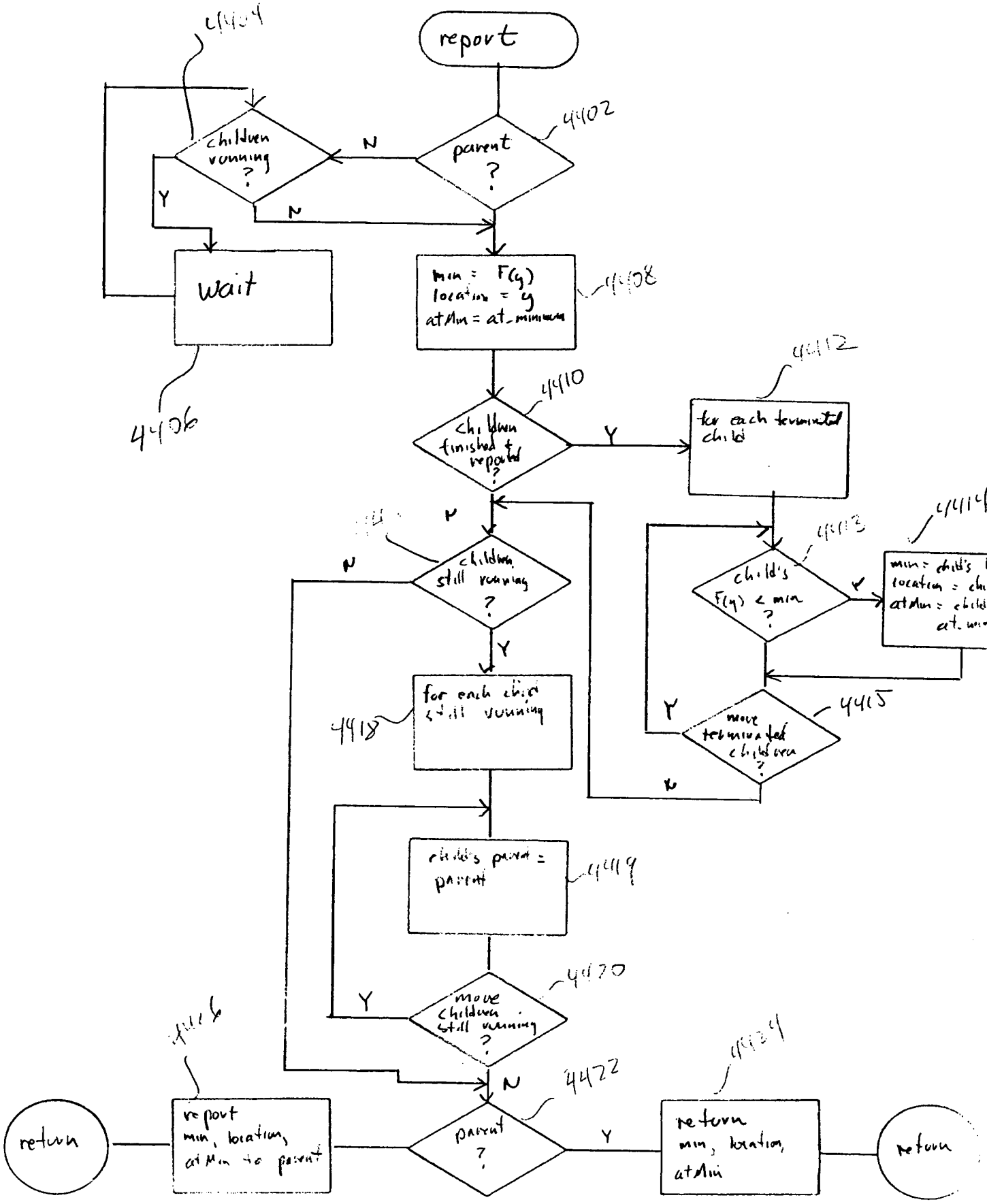

report
parent ?
4402
N
children running ?
Y
N
wait
4406
4404
min = F(y)
location = y
atMin = at_minimum
4408
children finished & reported ?
4410
Y
for each terminated child
4412
N
children still running ?
Y
for each child still running
4418
child's F(y) < min ?
4413
Y
min = child's F(y)
location = child's y
atMin = child's at_minimum
4414
move terminated children ?
4415
N
child's parent = parent
4419
move children still running ?
4420
Y
N
parent ?
4422
Y
return min, location, atMin
4424
report min, location, atMin to parent
4416
return
return

Figure 4A

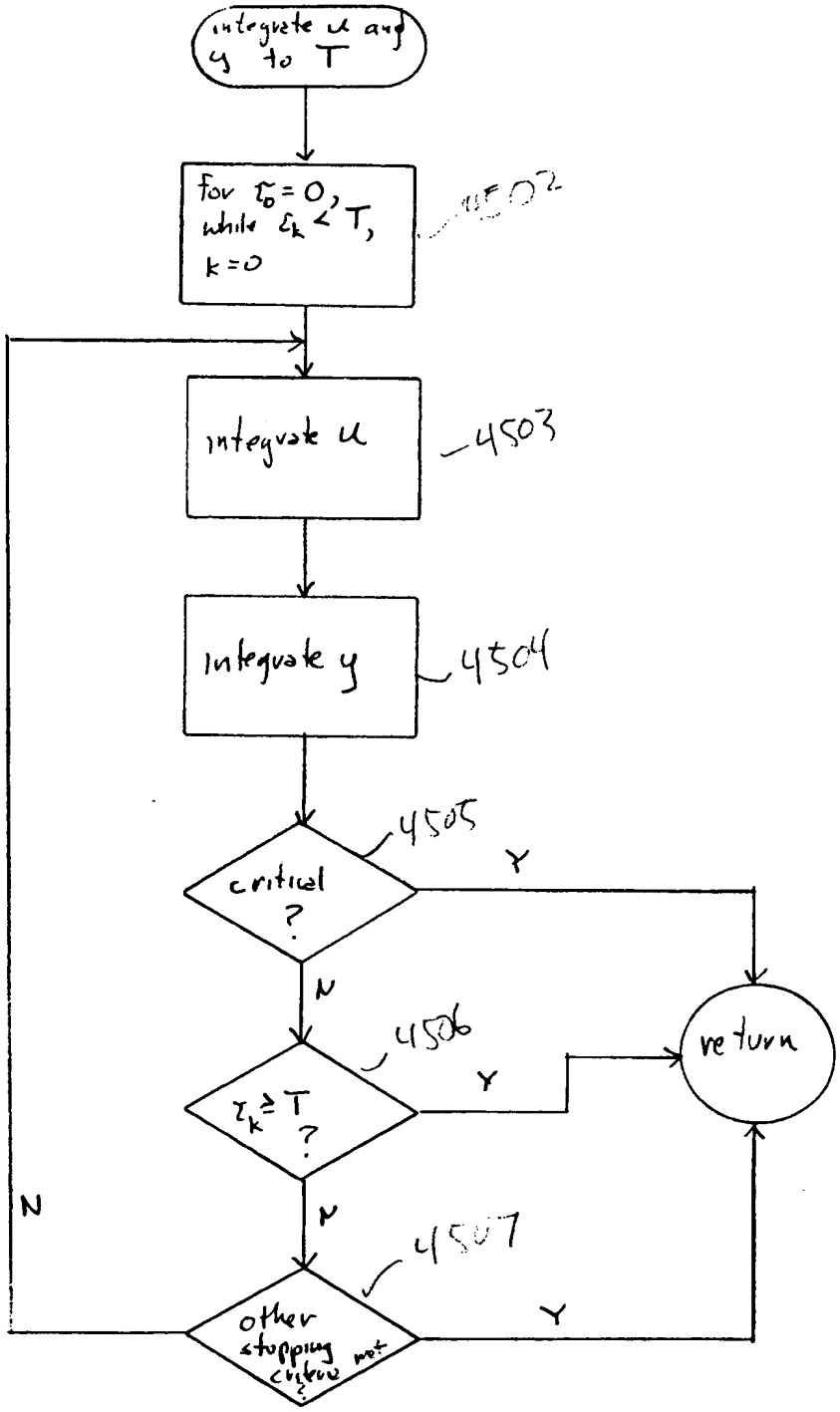

integrate u and y to T
for $\tau_0 = 0$, while $\tau_k < T$, $k = 0$
4502
integrate u
4503
integrate y
4504
critical ?
4505
Y
N
$\tau_k \geq T$?
4506
Y
return
N
other stopping criteria met ?
4507
Y
N

Figure 45

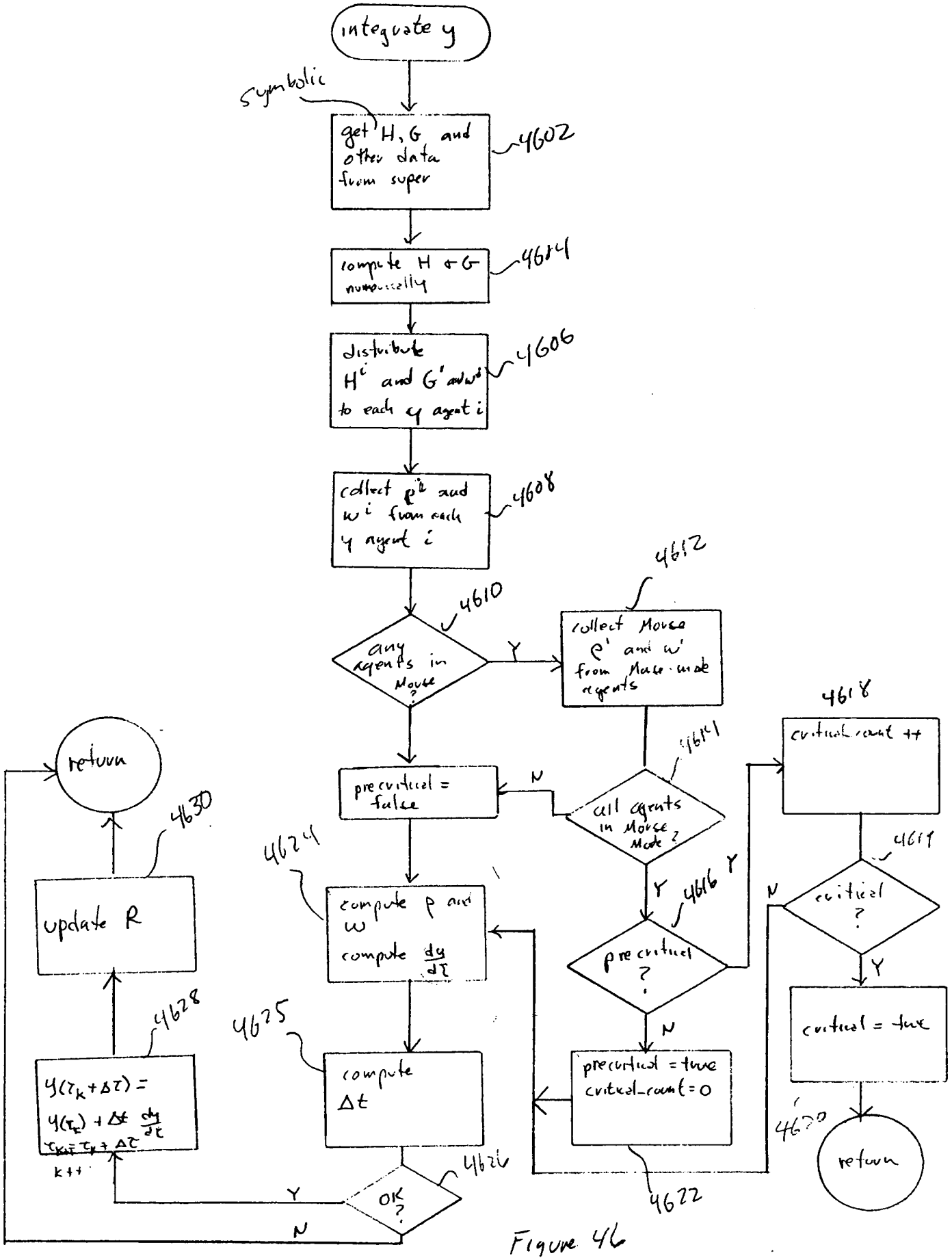

integrate y
symbolic
get H, G and other data from super
4602
compute H & G numerically
4604
distribute H^i and G^i and w^i to each q agent i
4606
collect p^i and w^i from each q agent i
4608
any agents in Mouse?
4610
Y
collect Mouse p^i and w^i from Mouse-mode agents
4612
N
precritical = false
all agents in Mouse Mode?
4614
Y
precritical?
4616
Y
N
critical_count ++
4618
critical?
4619
N
Y
critical = true
4620
return
precritical = true
critical_count = 0
4622
compute p and w
compute $\frac{dy}{d\tau}$
4624
compute Δt
4625
OK?
4626
Y
N
$y(\tau_k + \Delta\tau) = y(\tau_k) + \Delta t \frac{dy}{d\tau}$
$\tau_{k+1} = \tau_k + \Delta\tau$
k++
4628
update R
4630
return

Figure 46

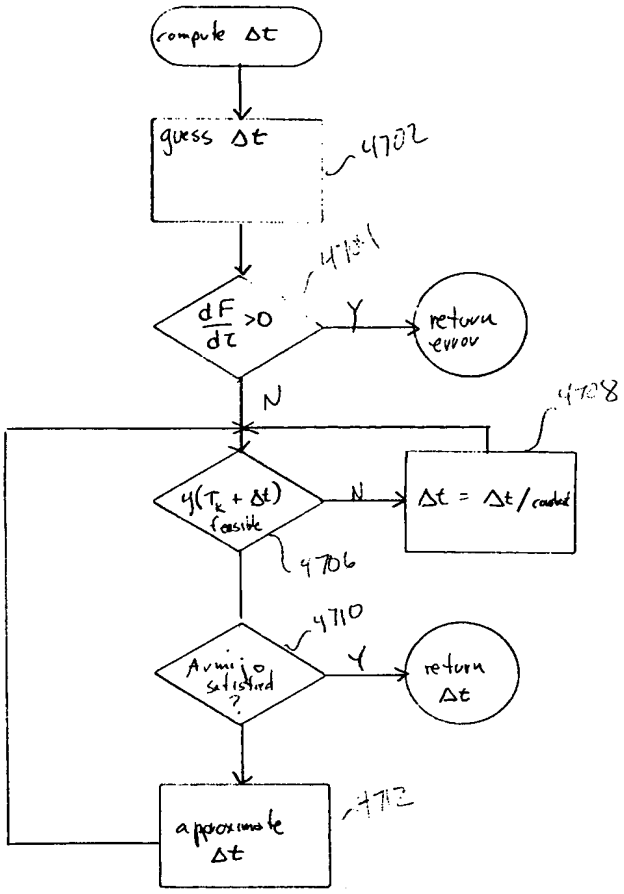

compute Δt
guess Δt
4702
dF/dτ >0
4704
Y
return error
N
4708
y(T_k + Δt) feasible
N
Δt = Δt / constant
4706
Armijo satisfied ?
4710
Y
return Δt
approximate Δt
4712

Figure 47

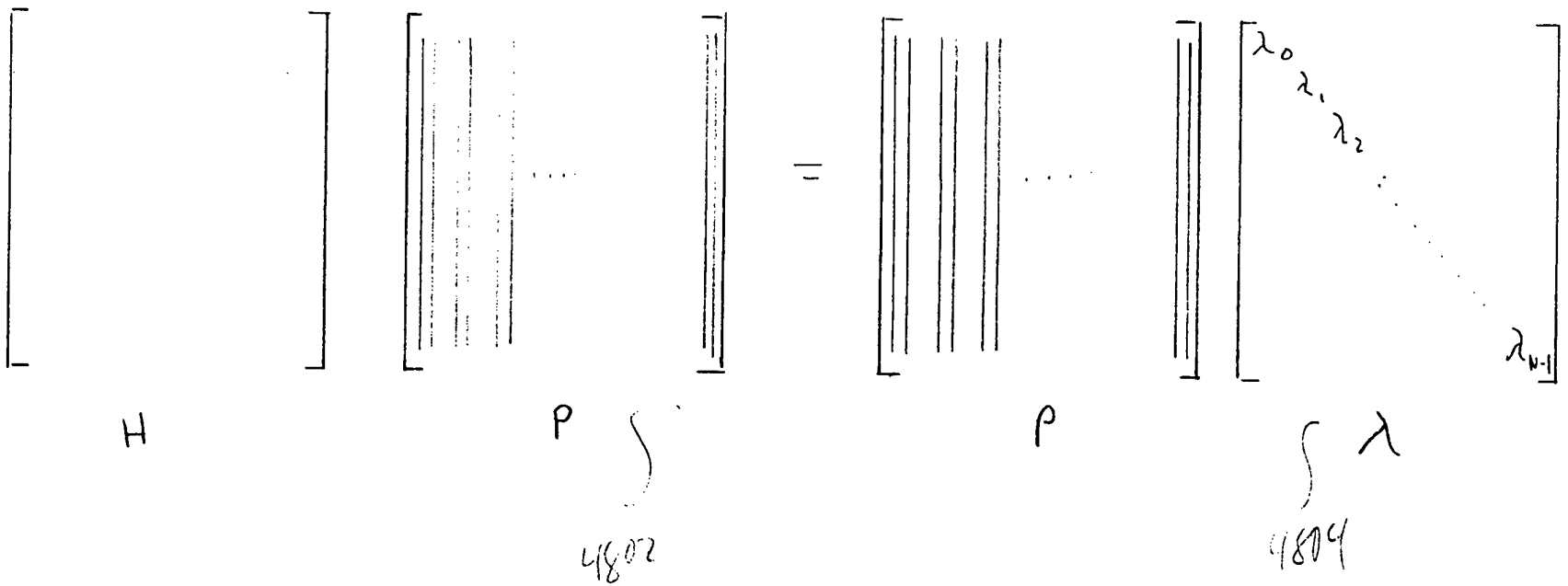


Figure 48

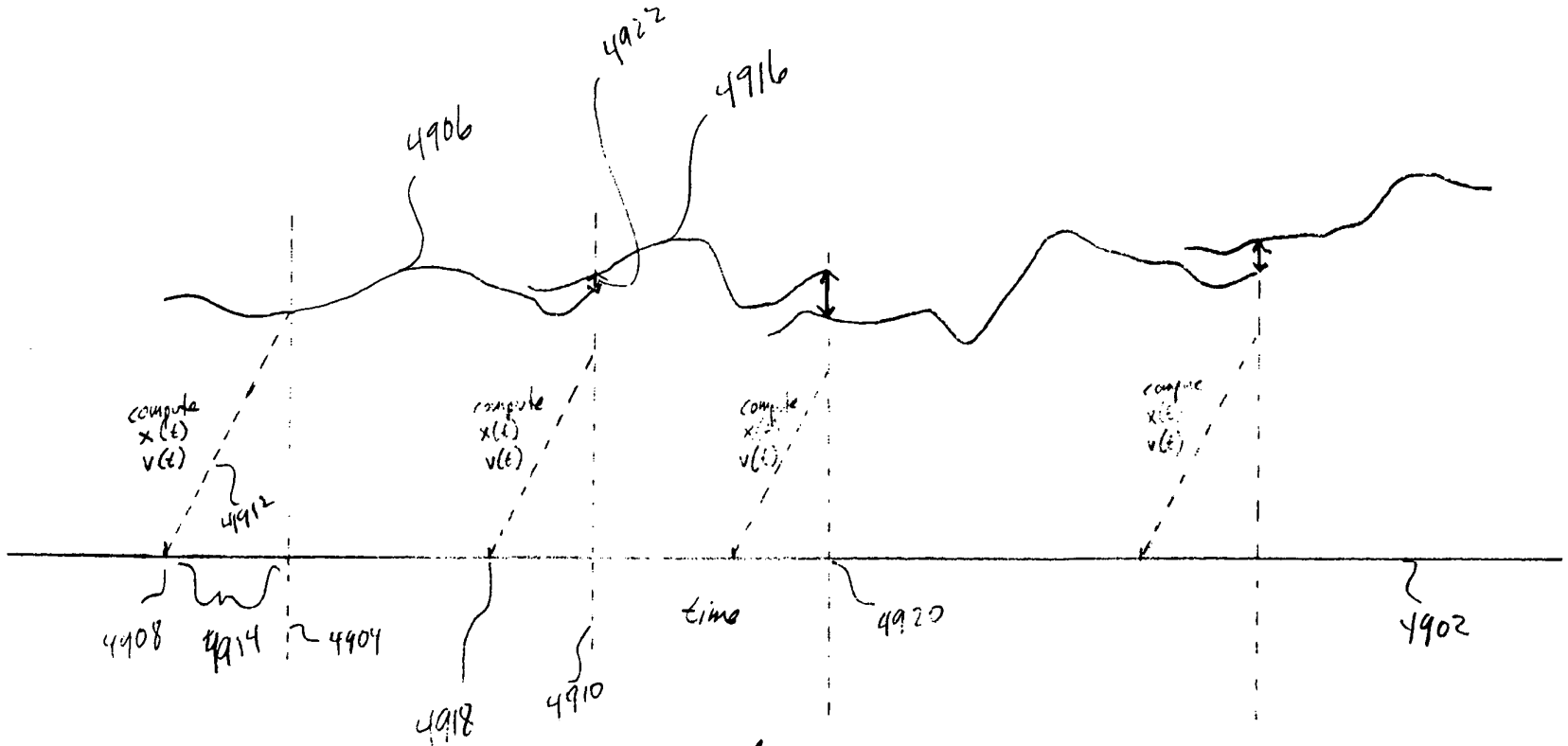

4912
4916
4906
compute
x(t)
v(t)
4912
4908
4914
4904
4918
4910
time
4920
4902

Figure 49

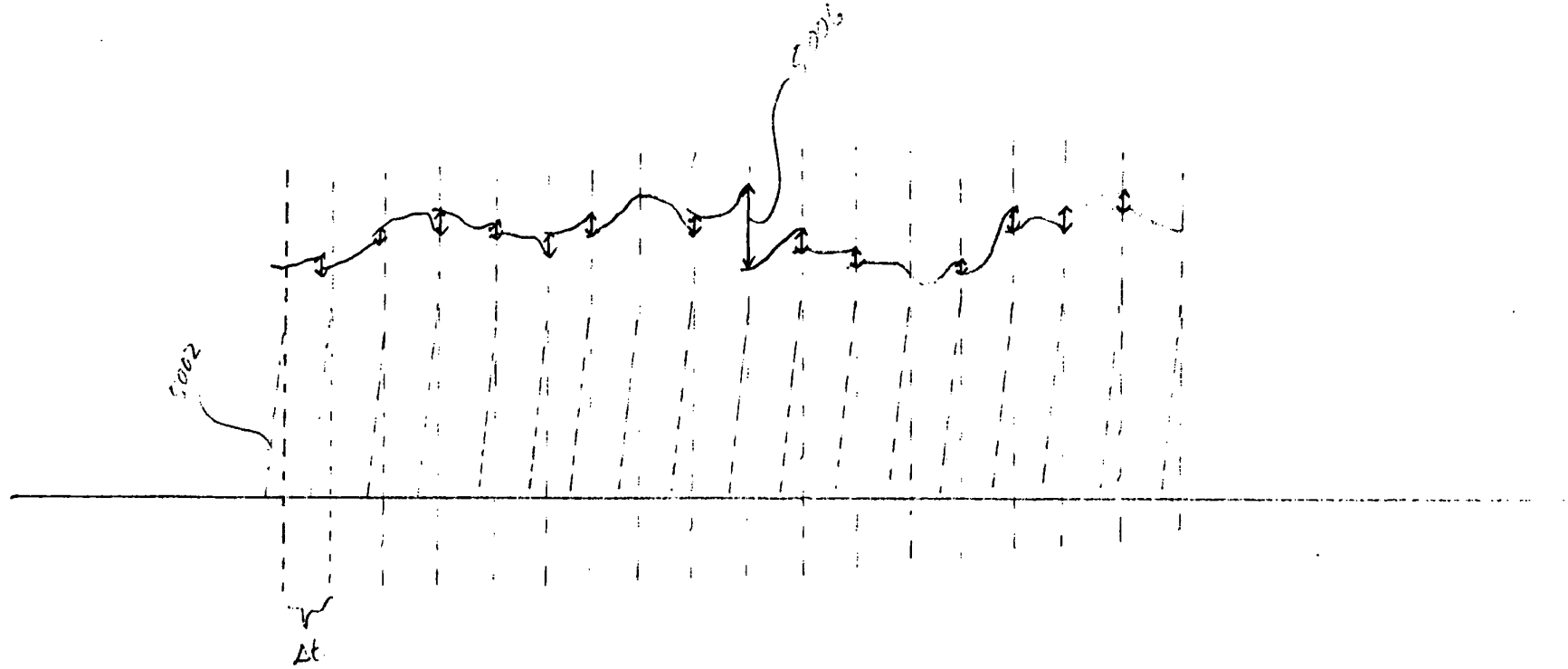


Figure 50

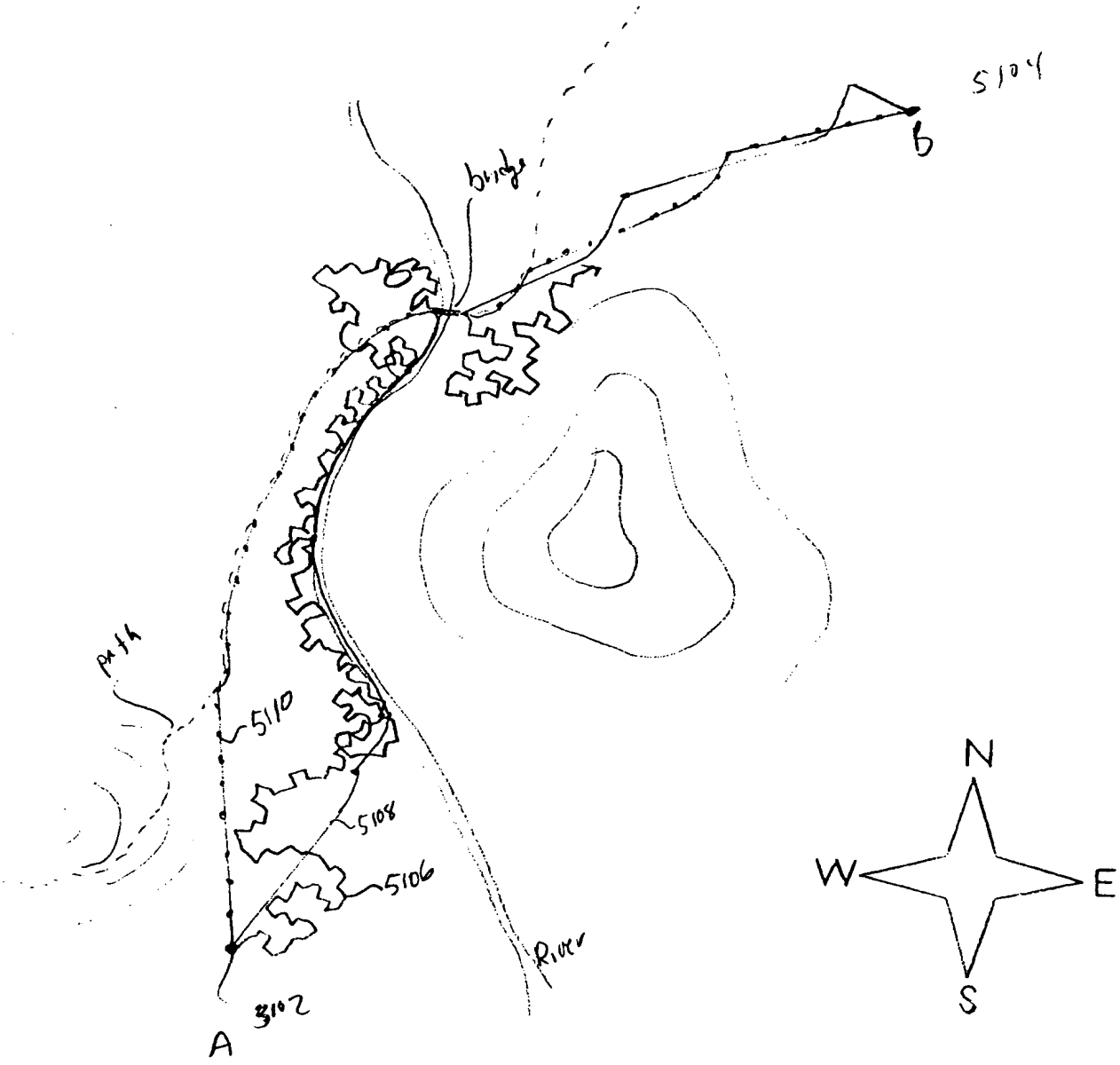


Figure 5.1

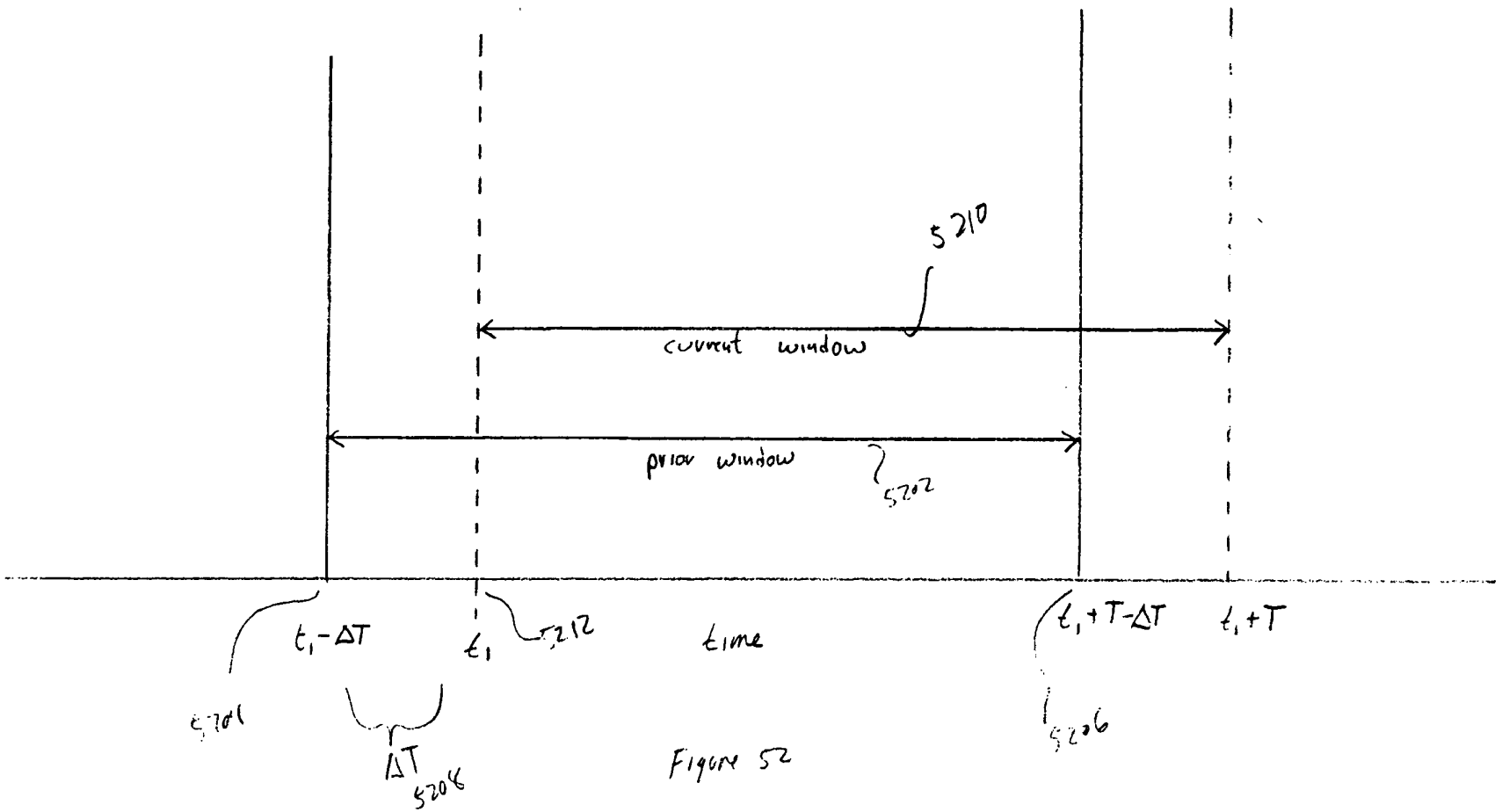

5210
current window
prior window
5202
$t_1 - \Delta T$
t_1
5212
time
$t_1 + T - \Delta T$
$t_1 + T$
5201
ΔT
5208
5206

Figure 52

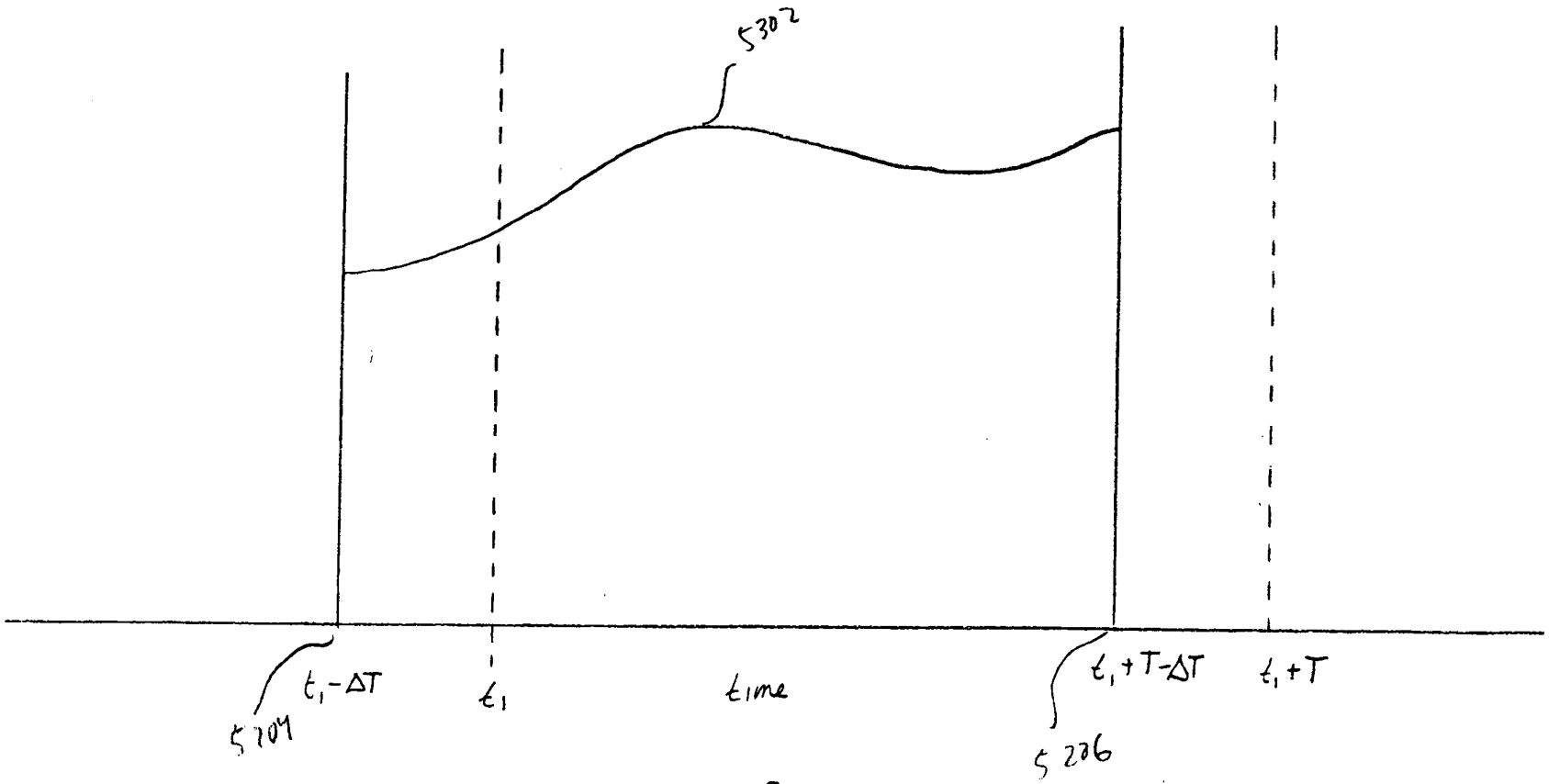


Figure 3

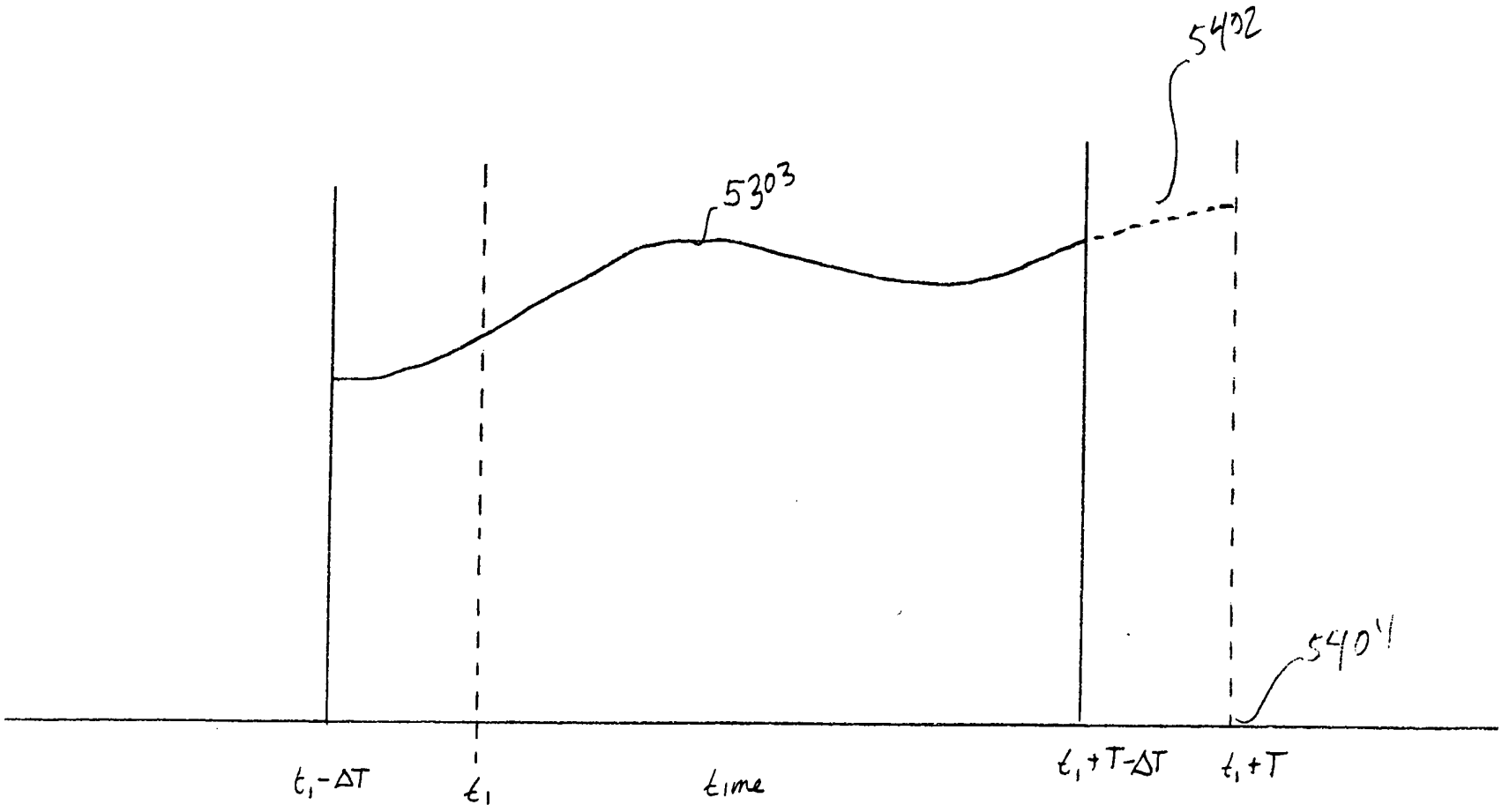


Figure 54

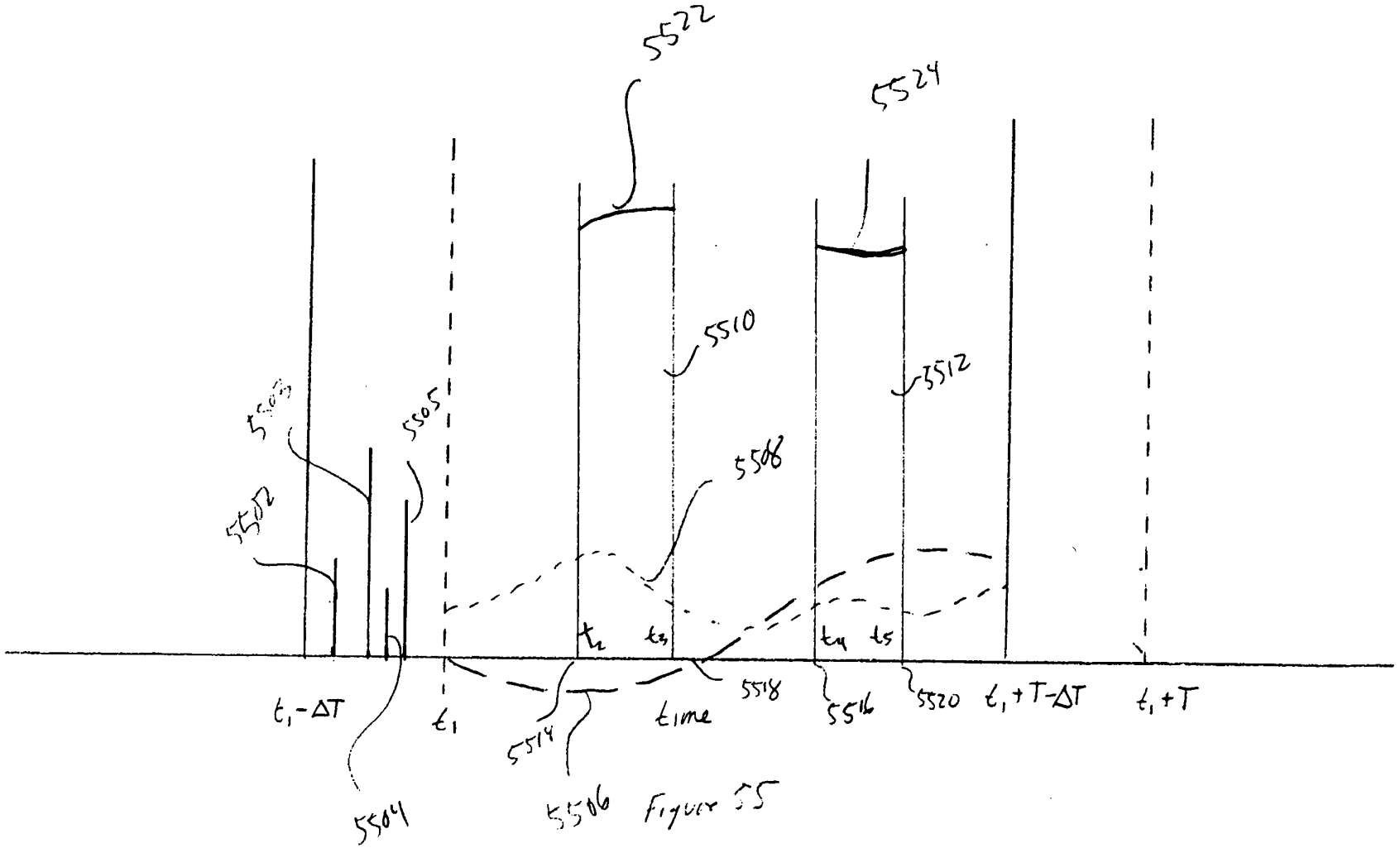

5522
5524
5510
5512
5508
5502
5505
$t_1-\Delta T$
t_1
time
t_2
t_3
t_4
t_5
5504
5506
5514
5518
5516
5520
$t_1+T-\Delta T$
t_1+T

Figure 55

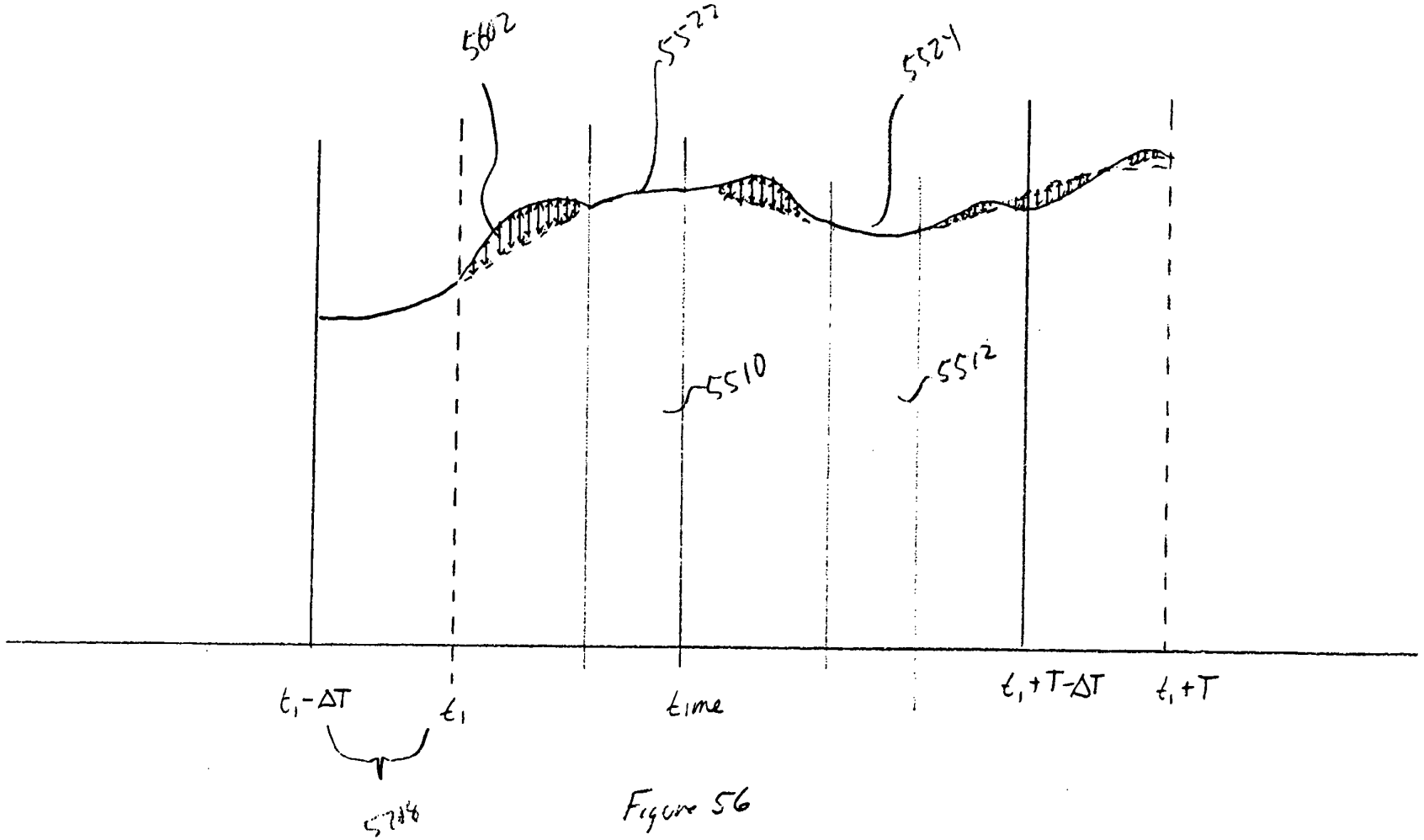

5602
5522
5524
5510
5512
$t_1 - \Delta T$
t_1
time
$t_1 + T - \Delta T$
$t_1 + T$
5786

Figure 56

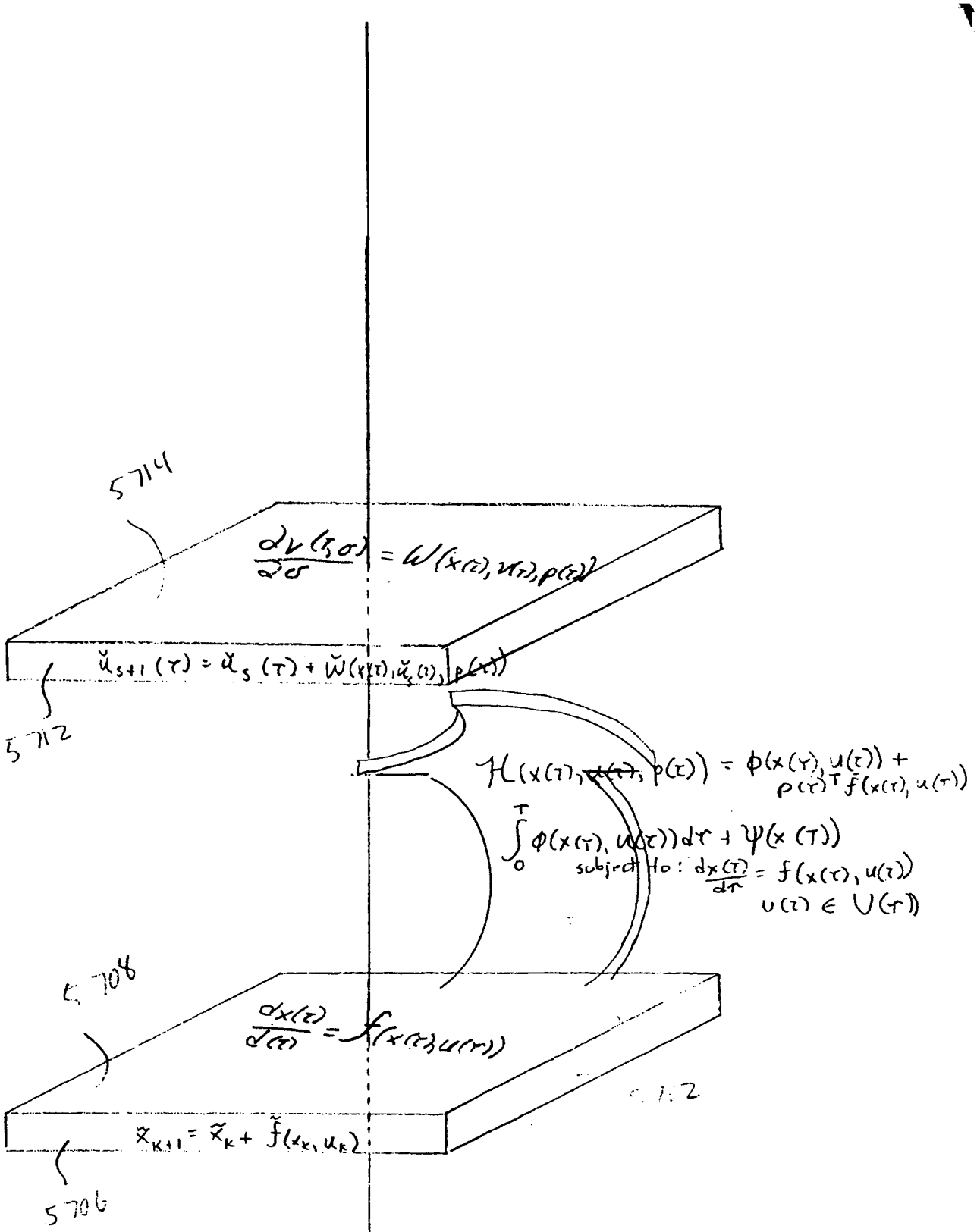

5714
$\frac{\partial V(\tau,\sigma)}{\partial \sigma} = W(x(\tau), u(\tau), \rho(\tau))$
$\check{u}_{s+1}(\tau) = \check{u}_s(\tau) + \check{W}(x(\tau), \check{u}_s(\tau), \rho(\tau))$
5712
$\mathcal{H}(x(\tau), u(\tau), \rho(\tau)) = \phi(x(\tau), u(\tau)) + \rho(\tau)^T \tilde{f}(x(\tau), u(\tau))$
$\int_0^T \phi(x(\tau), u(\tau))d\tau + \psi(x(T))$
subject to: $\frac{dx(\tau)}{d\tau} = f(x(\tau), u(\tau))$
$u(\tau) \in U(\tau)$
5708
$\frac{dx(\tau)}{d(\tau)} = f(x(\tau), u(\tau))$
5702
$\check{x}_{k+1} = \check{x}_k + \check{f}(x_k, u_k)$
5706

Figure 57

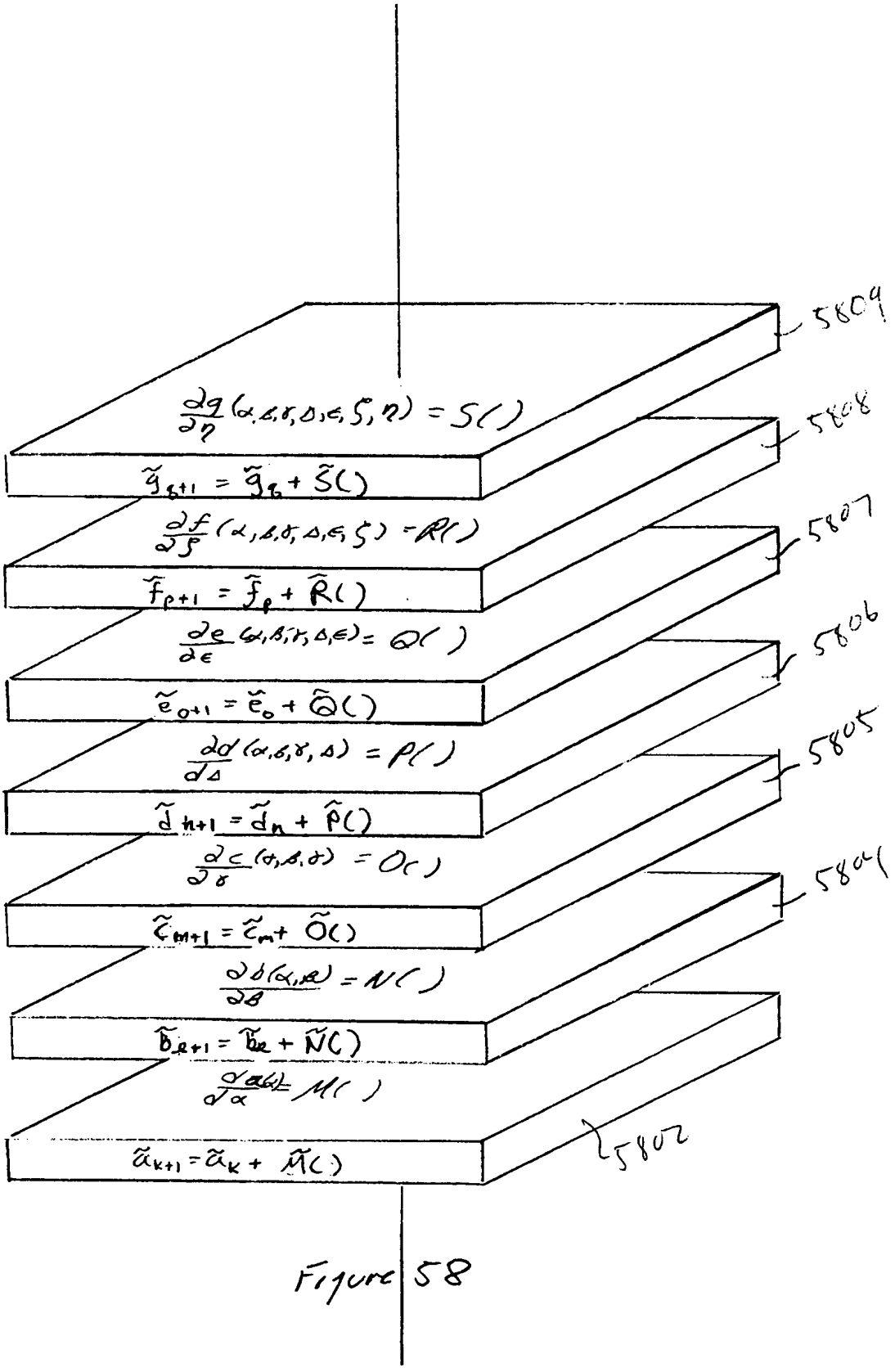

$\frac{\partial q}{\partial \eta}(\alpha,\beta,\gamma,\Delta,\epsilon,\zeta,\eta) = S()$
$\tilde{q}_{g+1} = \tilde{q}_g + \tilde{S}()$
$\frac{\partial f}{\partial \zeta}(\alpha,\beta,\gamma,\Delta,\epsilon,\zeta) = R()$
$\tilde{f}_{f+1} = \tilde{f}_f + \tilde{R}()$
$\frac{\partial e}{\partial \epsilon}(\alpha,\beta,\gamma,\Delta,\epsilon) = Q()$
$\tilde{e}_{e+1} = \tilde{e}_e + \tilde{Q}()$
$\frac{\partial d}{\partial \Delta}(\alpha,\beta,\gamma,\Delta) = P()$
$\tilde{d}_{n+1} = \tilde{d}_n + \tilde{P}()$
$\frac{\partial c}{\partial \gamma}(\alpha,\beta,\gamma) = O()$
$\tilde{c}_{m+1} = \tilde{c}_m + \tilde{O}()$
$\frac{\partial b}{\partial \beta}(\alpha,\beta) = N()$
$\tilde{b}_{l+1} = \tilde{b}_l + \tilde{N}()$
$\frac{\partial a}{\partial \alpha} = M()$
$\tilde{a}_{k+1} = \tilde{a}_k + \tilde{M}()$
5809
5808
5807
5806
5805
5804
5802

Figure 58